NICKEL/COBALT RECOVERY
FROM
MIDWEST RAFFINATE SOLUTION
- PROJECT FINAL REPORT -
VOLUME 1

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NICKEL/COBALT RECOVERY FROM MIDWEST RAFFINATE SOLUTION
PROJECT FINAL REPORT

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1.0 SUMMARY

The process which has been developed during this project is a viable method of recovering a radiation free concentrate of nickel and cobalt from Midwest raffinate solution. Impurities are first removed from the raffinate in a two stage precipitation process. The pure solution is then treated with sodium carbonate to recover a bulk nickel/cobalt carbonate precipitate for sale to a primary nickel producer. The product is free of any radioactive contamination with gamma emissions significantly below natural background. All other contaminants of concern such as arsenic, iron and aluminum have been removed to very low levels. The product has been evaluated by Falconbridge Limited and is acceptable for treatment at their Sudbury, Ontario smelter.

The process is expected to produce revenues of $4.25 million annually. With annual operating costs of of $1.5 million, the profit can be expected to be $2.75 million per year. A net capital expenditure of $4.21 million has been estimated, which means that the plant will be paid for after approximately 1.5 years. The process is an attractive one which can generate significant revenues and will pay back the capital investment in a very short period of time. The process has several fail-safe features built in which should ensure that no difficulties are experienced in selling the product.

It is recommended that a nickel/cobalt production facility be incorporated in any mill built to process the Midwest Joint Venture ore. It is also recommended that additional testwork be undertaken prior to design engineering. The most important area of investigation should be the use of lime as a precipitant instead of sodium carbonate. Significant cost savings can be realised if this switch can be successfully accomplished.

2.0 PROCESS TEST PROGRAM

The following section discusses the proposed recovery method and the research program which led to its development. All testwork was performed at Lakefield Research. Detailed results of the test program "An Investigation of the Recovery of Nickel and Cobalt from Midwest Uranium Raffinate" are presented in Lakefield Progress Reports No. 1 and 2 included as Appendix A of this report. Since the many variations in technique applied in developing the program are discussed in the Lakefield reports, this section of the report is presented as a summary.

2.1 Background

Extensive metallurgical research has been performed over the years to develop a process for recovering uranium from the Midwest deposit in Northern Saskatchewan. During the course of this research, a certain amount of information became available which suggested that recovery of nickel and cobalt from the uranium raffinate could be economically feasible. It was decided to undertake a test program which would investigate methods of separating nickel and cobalt from radioactive and other metal contamination to permit production of a saleable product.

An extensive literature study was carried out prior to initiation of the test program at Lakefield Research. This study suggested that three general approaches could be taken to the problem, with a large number of minor variations to each. The first, and simplest approach would be to selectively precipitate the impurities of concern, primarily arsenic, iron and radium, and then recover a bulk concentrate from the purified raffinate. The second approach would be to purify the raffinate and then remove the cobalt from the solution by solvent extraction producing pure nickel and cobalt solutions for further treatment. The third approach would be to precipitate all metals from solution and then selectively redissolve nickel and cobalt in ammoniacal solution. This solution would then be treated by solvent extraction of nickel, leaving cobalt for further treatment.

It was decided that only the first two approaches were worth pursuing. The third method was rejected primarily because of the difficulty in meeting effluent ammonia limits if such a process were instituted. In addition, since the reagents for use in this situation are selective for nickel over cobalt, it would have been possible to produce only a good quality nickel solution. The raffinate produced would have been a very poor quality cobalt solution which would have been difficult to treat further The alternate, sulphate based, solvent extraction system would produce relatively concentrated solutions of both nickel and cobalt with no deleterious effect on the environment.

Several process variations were reviewed and rejected as impractical. It was decided that it was not practical to produce either electrolytic cobalt or nickel, due to the relatively small reserves available and the high costs and other difficulties associated with the remoteness of the site. It was also decided that, since previous work had been unsuccessful in producing radium-free concentrates directly from untreated raffinate, solvent extraction of only purified raffinate would be investigated. Finally, only the raffinate was fully investigated as a source of metal values. Recovery of additional nickel and cobalt from the leach residue is possible, but development of a practical recovery method was not considered to be within the scope of this investigation.

2.2 Raffinate Pre-Treatment

As discussed above, both approaches to recovery of metals include purification of the raffinate. The raffinate contains significant concentrations of arsenic, iron, aluminum and radium, as well as minor amounts of zinc, most of which are undesirable to purchasers of a nickel or cobalt concentrate. Iron and aluminum are undesirable primarily because of the diluting effect they would have on precipitate grade at the high levels present in the raffinate. Zinc causes fuming in nickel smelters at relatively low levels. Arsenic and radium are undesirable for obvious reasons.

The method developed for removing impurities from the raffinate is similar to effluent treatment methods at existing Saskatchewan uranium operations, although pre-oxidation is employed to permit similar efficencies at lower pH levels. In the first stage the iron and arsenic are oxidized using hydrogen peroxide to permit complete precipitation of these elements in a stable form. The feed is then neutralized to pH 4.5 using calcium hydroxide with the addition of ferric sulphate. The sludge from this first stage contains most of the impurities of concern but also contains a significant percentage of the available nickel and cobalt. The precipitate is therefore washed with mildly acidic solution to redissolve the nickel and cobalt values. The wash filtrate is added to the partially treated raffinate.

The combined wash filtrate and partially treated raffinate stream is treated with barium chloride to remove radium and this slurry is neutralized with calcium hydroxide to a pH of 5.0 with further ferric sulphate addition as a final polishing step prior to metal recovery. The sludge from this step is recirculated to the process feed stream for redissolution of precipitated nickel and cobalt. The clarified solution produced is the feed to the next process step. The following sections summarize the test program used to develop the pre-treatment method.

2.2.1 First Stage Treatment

The general method described above was initially proposed following the literature study. Process feasibility and operating parameters were established during the first phase of the research. Initial studies to determine the optimum precipitation pH for the first step determined that complete removal of arsenic and iron was not possible without prior oxidation of both metal ions. Hydrogen peroxide was chosen as the preferred oxidant. An emf in excess of 600 mV was maintained in first stage precipitation for the remainder of the test program. No work was performed to optimize this level.

Initial testwork also determined that addition of ferric sulphate in a molar ratio of 1:1 Fe^{3+}/As was required to remove arsenic from solution. Operating experience in northern Saskatchewan has determined that approximately this level is required to generate a stable ferric arsenate sludge. No further optimization was attempted in this area.

Table 1, on the following page, illustrates the results of the first stage precipitation tests. The results indicate that a pH of between 4 and 5 is required to maximize removal of impurities while minimizing nickel and cobalt losses. It also indicates that addition of barium chloride during the first stage does not significantly improve the efficiency of radium removal. Based upon the results obtained in these tests, it was decided to use the first stage, at pH 4.5, without barium chloride addition, to remove arsenic and iron as well as most other impurities. The second stage would be used as a polishing step, to ensure complete removal of impurities prior to metal recovery.

Table 2.1: Summary of First Stage Precipitation Tests

				Precipitated (%)					
Test No.	Term. pH	$BaCl_2$ Add'n mg/L	$Fe_2(SO_4)_3$ Addition Fe^{+3}/As Molar Ratio	Al	As	Co	Fe	Ni	Ra226
1	3.0	0	0	12.2	15.4	5.3	51.5	3.4	52.4
	4.0	0	0	97.1	87.3	16.0	98.5	14.2	95.1
	5.0	0	0	99.9	88.3	20.0	99.7	17.0	98.1
	6.0	0	0	100.0	98.8	25.5	99.9	19.8	99.5
2	3.0	25	0	10.7	14.0	1.4	51.1	2.7	95.1
	4.0	25	0	94.7	84.5	8.2	98.6	1.1	99.0
	5.0	25	0	99.8	88.2	14.1	99.6	8.6	99.7
	6.0	25	0	100.0	90.4	22.5	99.9	18.4	99.9
3	3.0	0	0.5	16.0	77.1	6.7	97.3	2.6	90.6
	4.0	0	0.5	54.4	86.1	9.0	97.4	1.9	93.6
	5.0	0	0.5	99.6	92.06	14.2	98.6	9.1	97.4
	6.0	0	0.5	99.9	96.5	31.6	99.8	28.8	99.5
4	3.0	0	1.0	3.9	90.1	5.7	96.2	2.6	77.1
	4.0	0	1.0	25.3	91.8	9.2	97.1	4.3	88.3
	5.0	0	1.0	99.6	97.1	20.0	98.5	12.0	95.7
	6.0	0	1.0	100.0	99.0	38.2	99.9	30.4	98.9

Table 2.2: Summary of Repulp Tests for the Recovery of Co and Ni from First Stage Precipitate.

		Recovered in Solution (%)					
Test No.	Repulp pH	Al	As	Co	Fe	Ni	Ra_{226}
5	2.0	96	96	96	83	96	2.2
6	2.5	97	95	98	84	97	2.5
7	3.0	12	10	82	2.5	72	0.1
8	3.5	2.0	2.4	70	0.1	59	0.0

A series of tests were performed to evaluate the necessity of washing the sludge for recovery of precipitated metals. Table 2 illustrates the results of the repulp tests. Economic evaluation of the filtration alternative showed that unacceptable solution losses would occur if the thickened gypsum slurry were not filtered. The testwork, therefore, was used primarily to define operating methods. It is obvious that a pH below 3.0 would result in unacceptable redissolution of arsenic, aluminum and iron. At pH 3.5, recovery of nickel and cobalt began to drop significantly. A pH of 3.2 was selected for the wash solution in the following phase of the test program.

2.2.2 Second Stage Treatment

The second stage of treatment, as mentioned, was intended to be used as a polishing step. It was expected that, with the combination of pH 4.5 raffinate and pH 3.2 wash solution, the final pH would be close to 4.0. This pH was chosen, therefore for the next stage of treatment. Table 3 shows the results of barium chloride treatment at this pH. Although this work showed that 10 mg/L barium chloride was sufficient, it was decided to use the higher concentration of 25 mg/L to ensure complete removal in the next phase of testing.

Table 2.3: The Effect of Barium Chloride Addition During Second Stage Precipitation

			Precipitated (%)*					
Test No.	pH	$BaCl_2 \cdot 2H_2O$ mg/L	Al	As	Co	Fe	Ni	Ra_{226}
9	4.0	2	0.0	4.6	4.7	0.0	4.7	0.0
10	4.0	10	0.0	2.5	2.4	0.0	2.5	>75**
11	4.0	25	0.0	3.6	3.0	0.0	3.8	>75**
12	4.0	50	0.0	1.9	0.7	0.0	1.4	>75**

* Calculated from solution analyses

** Results were calculated based on the filtrate analyses at the detection limit of <0.03 Bq/L

Table 4 indicates the effect of varying the molar ratio of Fe^{3+}/As during second stage precipitation. Based upon this, it was decided to use a 4:1 ratio in the next phase of testing. Further testing showed that a final pH of 5.0 would be sufficient to remove most impurities in second stage precipitation; pH 6.0 however, would be slightly more efficient in removing zinc and aluminum. Further testing of a suitable pH range was left for future testwork. The sludge generated in this step contained a significant proportion of the nickel and cobalt. No further testing was performed during this phase since all of the sludge was intended to be recycled to the strongly acidic raffinate feed. The clarified solution generated in this pre-treatment step served as feed for the two test approaches described in the following sections.

Table 2.4: The effect of Fe^{+3}/As Molar Ratio During Second Stage Precipitation

			Precipitated (%)				
Test No.	pH	Fe^{+3}/As Molar Ratio	Al	As	Co	Fe	Ni
13	4.0	0.25/1	0.0	18	0.0	85	0.0
14	4.0	0.5/1	0.0	35	0.0	82	0.0
15	4.0	1/1	0.0	52	0.0	85	0.0
16	4.0	5/1	0.0	96	0.0	86	0.0

2.3 Bulk Precipitation Approach

The bulk precipitation approach was the simplest of the two methods used for recovery of nickel and cobalt from the pre-treated raffinate. Nickel and cobalt were precipitated from the purified raffinate using a variety of reagents to form a bulk concentrate. The tests evaluated three reagents as precipitants; sodium hydrogen sulphide, calcium hydroxide and sodium carbonate. Table 5, on the following page, summarizes the test results.

Sodium hydrogen sulphide was not efficient in removing nickel and cobalt from solution at stoichiometric addition levels. Much higher levels would be required for complete recovery. This could result in environmental difficulties and increased costs during operation due to overconsumption of reagent.

Calcium hydroxide was more efficient in precipitating metals from solution and produced an easily handled filter cake. However, the high level of calcium in the product reduced the nickel/cobalt grade to approximately half that of the other reagents. Also the reagent is completely non-selective, precipitating all metals in solution.

Sodium carbonate was very efficient in removing metals of value from solution. It also has the advantage of being relatively selective, since it does not not precipitate uranium from solution, reducing the chance of contamination in the case of circuit upset. The precipitate produced in the first test, performed at ambient temperature, exhibited poor filtration characteristics. A second test was performed at 50°C producing a much higher quality cake.

It was concluded that sodium carbonate and calcium hydroxide were both adequate precipitants. Sodium carbonate was chosen for the next phase of the work on the basis that it had a a higher probability of producing a concentrate which could be supplied directly to a refinery. It was also felt that the additional reagent costs associated with it would be offset by increased transportation costs of the hydroxide precipitate due to its lower grade.

Table 2.5: Summary of Cobalt-Nickel Precipitation Tests

	Analyses (%)			
Element	Co-Ni Sulphide	Co-Ni Hydroxide	Co-Ni Carbonate (Test No. 1)	Co-Ni Carbonate (Test No. 2)
Al	0.05	0.07	0.09	0.08
As	0.66	0.27	0.29	0.04
Ca	0.04	16	4.1	4.8
Co	3.6	2.0	4.2	3.46
Fe	0.03	0.03	0.03	0.10
Mg	0.04	1.8	0.68	1.6
Ni	38.8	20.8	41.8	36.1
U	0.00033	0.00017	0.002	0.00033
Zn	0.1	0.06	0.12	0.13
Ra_{226} (Bq/g)	0.05	0.05	0.01	0.04
Wet wt. (g)	35.0	101.4	81.1	110.7
Dry wt. (g)	7.3	30.7	13.7	15.5
Co precip. (%)	49.2	99.9	98.3	99.7
Ni precip. (%)	48.1	100.0	98.2	99.6

2.4 Solvent Extraction Approach

Purified raffinate was used to generate extraction isotherms for three solvent extraction reagents, Ionquest 801 and Cyanex 272 and 302. Complete details of these tests are included in Appendix A. Cyanex 272 was effective in separating nickel from cobalt in the pH range of 4 to 5. At pH 4.5 extraction of cobalt was 77% with no coextraction of nickel. Cyanex 302 was also effective, but in a much lower pH range, which would require considerably higher acid consumption in an operating circuit. Ionquest 801 did not perform as well as the other two reagents. Only Cyanex 272 was investigated further. The extraction isotherm showed that five stages of extraction would be required to extract cobalt from the expected grade of feed solution.

A large sample of loaded organic was made up to permit generation of a stripping isotherm. The isotherm showed that only a single stage was necessary to achieve complete stripping. Larger scale tests were performed, generating sufficient volumes of strip liquor and cobalt raffinate to permit production of concentrates for analysis. Table 6 shows the results obtained in these tests. In the batch tests only a single extraction step was used, resulting in less than complete extraction of cobalt and some coextraction of nickel. In a continuous circuit this would not be expected.

Table 2.6: Analyses of Cobalt Raffinate, Strip Liquor and Loaded Organic

	Analyses (mg/L)		
Element	Co-Ni Raffinate	Strip Liquor	Loaded Organic
Al	<0.10	21	11
As	4.8	<10	0.7
Ca	468	596	91
Co	128	13750	550
Fe	<0.02	1.36	1.6
Mg	512	1120	45
Ni	3960	639	17
Zn	0.02	185	27
pH	4.5	1.7	--

Both the cobalt raffinate and the strip liquor were used to generate final concentrates. The respective solutions were used to produce relatively pure nickel and cobalt carbonate products. Table 7 presents the results obtained from these tests. The results demonstrate that good quality concentrates can be generated with low levels of aluminum, arsenic, iron, zinc, uranium and radium. Some cross-contamination of the metal values occurred, however, as discussed above, this would not be expected in a continuous process. The only significant levels of contamination came from calcium and magnesium.

Table 2.7: Nickel and Cobalt Product Analyses

	Analyses (%)	
Element	Nickel Carbonate (Test No. 24)	Cobalt Carbonate (Test No. 25)
Al	<0.10	0.30
As	0.046	0.02
Ca	4.43	1.42
Co	1.51	40.2
Fe	<0.05	0.05
Mg	2.28	1.78
Ni	39.4	1.90
Zn	0.00005	0.00013
U	0.004	0.52
Ra_{226} (Bq/g)	0.02	0.08

2.5 Process Selection

Following completion of the first phase of the test program, preliminary design criteria were developed for the two approaches which had been determined to be most attractive. Order of magnitude capital and operating costs were estimated for the common raffinate purification circuit followed by separate estimates for the bulk precipitation and solvent extraction options. Gross revenues which could be expected from the operation at conservative recovery levels were also estimated. Flow diagrams for the process alternatives assessed are presented in Figures 1, 2 and 3 on the following pages. It should be noted that the choice of drum filters for use in sludge filtration was arbitrary. Evaluation of the filter choice was left for the second phase of the research program. The cost and profit estimates for the various alternatives are summarized in Appendix E.

The conclusion reached was that the bulk precipitation circuit would be a profitable operation, providing a more than adequate return on investment. The increased cost associated with the more complex solvent extraction circuit could not, however be justified.

Essentially, the increased operating costs of this circuit nearly matched the increased metal value. With limited additional return, the increased capital outlay greatly reduced the return on investment. While the solvent extraction circuit was technically practical, it was not economically feasible.

It was decided, therefore, to concentrate upon the bulk precipitation approach in the second phase of testwork. The lock-cycle and large scale test programs in this second phase would more fully investigate the raffinate purification technique described in Section 2.2 and presented in Figure 1. It would also include more complete testing of bulk precipitation using sodium carbonate as described in Section 2.3 and presented in Figure 3.

2.6 Lock-Cycle Tests

Two separate lock-cycle tests were conducted for six cycles to simulate continuous operation of the raffinate purification circuit illustrated in Figure 1. The variable tested in the duplicate tests was the pH of operation in the second stage (polishing) precipitation. The first test was performed at a final purified raffinate pH of 5.0, the second at pH 6.0. Cycles 1 to 3 of both tests were performed with a low wash ratio in the first stage precipitate acid wash. Cycles 4 to 6 used a high wash ratio. Table 8 on the following page summarizes the test results. The data clearly indicates that optimum nickel/cobalt recovery can be accomplished by operating the circuit at the lower pH in second stage precipitation while maintaining a high wash ratio in the first stage acid wash filters. The zinc in the raffinate was not efficiently removed , although it did not accumulate to any significant degree. This could be a source of difficulty if there were any significant quantities of high zinc material processed in the mill. No impurities of concern were observed to build up during the lock-cycle tests.

Following Cycle 6 of each test, the purified raffinate was precipitated to form a bulk nickel/cobalt carbonate concentrate. The solutions were heated to 50°C and neutralized to pH 8.6 with 200 g/L Na_2CO_3. After 30 minutes reaction time the precipitates were filtered, dried and analyzed. Results are presented in Table 9 below.

Table 2.8: Summary of Locked Cycle Purification Tests

				Percentage Removed from Solution (%)					
Test No.	Cycle No.	Wash Ratio Wash Vol/Bed Vol.	2nd Stage pH	Al	As	Co	Fe	Ni	Zn
1	3	0.6/l	5.0	99.2	100.0	12.5	98.5	11.1	0.0
1	6	2.0/l	5.0	99.2	98.3	7.9	98.6	6.2	0.0
2	3	0.6/l	6.0	99.9	100.0	13.8	100.0	13.2	12.4
2	6	2.1/l	6.0	99.9	99.0	12.2	99.0	10.4	19.21

Table 2.9: Analyses of Cobalt-Nickel Carbonate Product

	Analyses (mg/L)	
Element	Test No. 1	Test No. 2
Al	0.1	0.1
As	0.6	0.3
Ca	5.7	6.2
Co	3.0	3.1
Fe	0.4	0.2
Mg	2.0	1.9
Ni	31.2	30.9
Zn	0.2	0.3
U	0.00017	0.00008
Ra_{226}	0.02 Bq/g	0.02 Bq/g

It should be noted that calcium and magnesium levels are both higher than in the testwork performed in the first phase. This probably accounts for the lower nickel and cobalt concentrations in the two precipitates. Both products were still very low in radium and uranium and both constitute saleable concentrates.

2.7 Large Scale Test

Two 50 kg batches of Midwest ore were pressure-leached, filtered and washed to generate a uranium pregnant solution. This solution was stripped of uranium in a batch solvent extraction procedure to generate a representative uranium raffinate. The solution had been diluted at an earlier stage to provide a raffinate concentration of 2.32 g Ni/L, which was felt to be closer to predictions of actual plant solution strength. This raffinate was treated in a semi-continuous manner simulating as closely as possible the flowsheet developed in previous testing. The flowsheets are illustrated in Figures 1 and 2. Each unit operation, i.e. first and second stage purification and cobalt/nickel precipitation, was performed continuously in a simulated circuit. A total of 625 L was treated to produce sufficient quantities of final product for testing by primary producers.

Table 10 on the following page presents the solution and precipitate assays generated during the large scale test. It can be seen that, as in previous tests, the method is very effective in removing arsenic, aluminum, iron and radium from solution. It is also effective in removing low levels of uranium from solution.

Samples of the slurries produced in the three unit processes were recovered for thickening and filtration studies. This work was performed by a representative of EIMCO Process Equipment, Mr. W. Stone. The report from EIMCO was used to generate specifications for plant process equipment described in Sections 4 and 5 of this report. The EIMCO report is included as Appendix B. It should be noted, however, that EIMCO recommended the use of a horizontal belt filter for washing the first stage precipitate. This change has been incorporated in the final design (see Figure 4 and detailed flowsheets in Appendix C).

Table 2.10: Analyses Comparing the Raffinate and Purified Raffinate Solution

Element	1st Stage Precipitate (%)	2nd Stage Precipitate (%)	Raffinate (mg/L)	1st Stage Solution (mg/L)	Purified Raffinate 2nd Stage Solution (mg/L)
Al	1.93	0.64	1290	0.80	0.56
As	4.81	0.37	4170	0.63	0.49
Co	0.074	0.18	254	172	159
Fe	6.71	31.2	1320	1.81	1.66
Ni	0.69	2.18	2320	1360	1250
U	0.023	0.009	17.2	<1	<1
Zn	0.11	0.27	101	39	33
Ra_{226}	-	-	-	-	0.16 Bq/L*

* The radium assay was reported after 24 hours. The actual result after one week would be lower.

Table 11 shows the analysis of the final product from the large scale test.

Table 2.11: Analyses of the Cobalt-Nickel Product

Element	Analyses (%)
Al	<0.10
As	0.004
Ca	10.5
Co	2.26
Fe	0.029
Mg	1.06
Ni	18.6
U	0.0006
Zn	0.64
Ra_{226}	0.03 Bq/L

It will be noted that nickel and cobalt in the concentrate are much lower than in previous work while calcium is much higher. This could be because of the lower feed grade of the solution. More probably, it is due to inefficiencies encountered in the design of the large scale equipment. Proper reagent addition has been a persistent problem at Lakefield Research in large scale studies. It is felt that the grades achieved in the lock-cycle tests are more representative of what can be achieved in actual practice (see Table 9).

2.8 Miscellaneous Testwork

2.8.1 Flotation

A significant portion of the nickel and cobalt in the Midwest ore does not dissolve under the conditions designed to recover uranium in the pressure leach circuit. It has therefore been suggested that it may be worthwhile to recover the remaining nickel and cobalt minerals by flotation of the leach residue. This flotation concentrate would be releached under different conditions to dissolve the nickel and cobalt. The dissolved metals could then be treated in the circuit already in place for recovery of a nickel/cobalt concentrate. Lakefield Research performed preliminary scoping tests to determine whether there was any potential for flotation recovery. These tests provided encouraging recovery results for the metals of interest. No further testwork was undertaken, since it did not fall within the scope of this research program.

2.8.2 Hydroxide Concentrate

If the results presented in Table 11 are representative of what can be expected in actual practice, the economics of the decision to pursue carbonate rather than hydroxide precipitation may be changed slightly. To ensure that sufficient information was available to make this decision prior to any future test program, a further small-scale precipitation of purified raffinate from the large scale test was performed using calcium hydroxide. Results from this test are incomplete due to limited funding. However, cobalt and nickel grades were comparable to those achieved using carbonate. The alternative production of a hydroxide concentrate should be pursued further.

2.8.3 Uranium Contamination

To determine the effectiveness of the process in removing uranium, an upset condition was simulated by the addition of uranium to the feed. Details of this test are presented in Appendix A, Progress Report No. 2, Figure 5, p.18. The procedure was shown to be extremely effective in removing uranium but some contamination did enter the final product. The contamination of the feed was at such a high level that a small quantity did reach the product, however, it is not reasonable to expect that such a high level of uranium in raffinate would ever be experienced in practice. A serious plant upset condition would be expected to result in feed contamination of perhaps one tenth of the level actually added in the test. The envisaged process can be expected to accomodate typical upset conditions in the raffinate feed.

2.9 Further Testwork

2.9.1 Optimization

The most important area to be investigated is the optimum precipitant. The use of lime rather than sodium carbonate may have a significant impact upon process economics (see Section 8.2). This alternative should be closely investigated in any future test program.

Very few of the operating parameters of this process were optimized during this program due to the limited scope of work. The potential additional return from nickel and cobalt using existing parameters is sufficient to justify installation of a nickel and cobalt recovery circuit as part of a new uranium facility at Midwest. However, it is recommended that, prior to commencement of detailed engineering, additional metallurgical testing be undertaken to optimize various process variables. The most important variable from an engineering point of view is retention time in the various treatment stages. A standard 30 minute retention time was used for all treatment steps in the test work and was used for design of the conceptual process (See Section 4). It may be possible to reduce tankage and floor space expenditures if a shorter retention time is possible. This variable should therefore be investigated further.

First and second stage precipitation pH levels were only partially investigated during the test work. This variable has, however, a large potential impact upon nickel and cobalt losses. More precise information is therefore required prior to design engineering.

Ferric sulphate addition is a significant expenditure in this design. To minimize this expenditure, additional testing should be undertaken to optimize addition rates. Barium chloride and hydrogen peroxide, although less significant, are costly reagents whose consumption should also be optimized.

2.9.2 Uranium Contamination

Another series of small scale tests should be carried out to determine the sensitivity of the process to uranium circuit upset. Previous tests have used a typical raffinate level of 17 mg/L U_3O_8, which was easily handled, and a very high level of 697 mg/L which was not. More realistic levels of uranium contamination should be used to determine the maximum level of contamination which the circuit can handle. Possible ameliorative actions should also be investigated to determine an appropriate response to high feed uranium concentration.

2.9.3 Flotation

The exact methods and reagents used in the Lakefield Research flotation tests should be obtained for use in generating an order of magnitude estimate of costs and returns from leach residue treatment. If this exercise shows any potential for profit in developing a recovery method for the nickel and cobalt in the residue, further testing should be performed. This work would consist of a series of flotation tests to determine proper reagent additions and flotation conditions. It should also determine optimum leaching methods for the flotation concentrate produced.

3.0 PROCESS DESCRIPTION

The process description is essentially similar to that laid out in Section 2. The following sections describe the main parts of the process as it will operate in the proposed circuit.

3.1 Raffinate Pre-Treatment

The uranium raffinate will be pumped to the nickel/cobalt recovery circuit after it has passed through the raffinate aftersettler for complete removal of organic. The raffinate pre-treatment flowsheet is illustrated in Figure 4.

3.1.1 First Stage Precipitation

The raffinate will enter the pre-oxidation pachuca where hydrogen peroxide will be added to maintain a solution emf of 600 mV. All reaction vessels will be air-agitated pachucas, both for reasons of economy and to help maintain an oxidizing environment. Recycled second stage precipitate will also be added into this pachuca to recover any precipitated nickel and cobalt (see Section 3.1.2). Retention time in all treatment pachucas is 30 minutes.

The oxidized raffinate will then flow by gravity into the first stage precipitation pachuca. Ferric sulphate will be added in a 1:1 molar ratio of Fe^{3+}/As, and the mixture will be neutralized to pH 4.5 with lime. It is anticipated that, because of variable feed concentrations, it will be difficult to maintain arsenic removal efficiency in this step. To ensure adequate solution purity, second stage precipitation will have sufficient ferric iron dosage to catch any remaining arsenic.

The slurry from first stage precipitation will be thickened. The thickener overflow will advance to second stage treatment, the underflow will be pumped to a horizontal belt filter. The sludge will be filtered and washed in a countercurrent fashion with acidified (pH 3.2) water to redissolve precipitated nickel and cobalt. The washed precipitate will be repulped and pumped to the uranium circuit for disposal with the main process tailings. The filtrate will be recycled to the thickener feed to dilute the feed slurry to the correct density (2-4 % solids).

3.1.2 Second Stage Precipitation

The thickener overflow from first stage precipitation will be pumped to a third pachuca where barium chloride will be added at a dosage of approximately 25 mg/L of feed. This will remove any remaining radium from solution. This slurry will flow by gravity to a fourth pachuca where ferric sulphate will be added at a dosage of 0.10 kg Fe^{3+}/L of feed. The mixture will be neutralized to pH 5.0 and the resulting slurry will flow by gravity to a reactor-clarifier.

The clarifier underflow will be partially recirculated, if necessary, to ensure a maximum density for discharge. This thickened flow will be recycled to the first pachuca in the circuit to allow any precipitated nickel and cobalt to redissolve in the strongly acidic raffinate feed. The clarifier overflow will be further clarified in sand filters prior to final product precipitation.

3.2 Nickel/Cobalt Bulk Precipitation

The bulk precipitation flowsheet is presented in Figure 5. The pure, clarified raffinate from pre-treatment will be pumped through a heat exchanger to raise the solution temperature to 50°C. The solution will then be neutralized in a fifth pachuca to pH 8.65 using sodium carbonate solution. The temperature will be maintained at a constant level by steam injection if necessary. The slurry will then flow by gravity to a reactor- clarifier. Once again the clarifier underflow will be recirculated as necessary to maximize sludge density. The clarifier overflow will be pumped to second stage effluent treatment in the uranium circuit to ensure complete treatment prior to discharge to the environment.

The clarifier underflow will be pumped to a sludge holding tank. The thickened sludge will be pressure filtered to ensure minimum cake moisture. The moist cake will be packed in one ton tote bags for shipment to the purchasing primary producer.

4.0 PROCESS DESIGN CRITERIA

4.1 Raffinate Feed Analysis

Typical analysis of the raffinate stream feeding the nickel-cobalt recovery circuit is as follows:

Analyte	g/L
Ni	2.29*
Co	0.24*
As	4.2
Al	1.3
Fe	1.3
Zn	0.10
U	0.001

* based on 50% of the nickel and 50% of the cobalt in the mill feed (5.14 t/h at 3.47% Ni and 0.37% Co) being recovered to the raffinate stream (39 m^3/h) feeding the nickel-cobalt recovery circuit.

4.2 Production Criteria

Raffinate Stream to Ni/Co Recovery Circuit, m^3/h		39.0
Nickel Recovery, %	- Raffinate Pre-Treatment	93.8
	- Bulk Precipitation	99.7
	- Overall Recovery from Raffinate	93.5
Cobalt Recovery,%	- Raffinate Pre-Treatment	92.1

	- Bulk Precipitation	99.8
	- Overall Recovery from Raffinate	91.9
Bulk Precipitate Analysis, %	- Ni	30.0
	- Co	3.14
	- Al	0.1
	- As	0.6
	- Ca	5.7
	- Fe	0.4
	- Mg	2.0
	- Zn	0.2
	- U	0.00017
	- Ra_{226}(Bq/g)	0.02
Bulk Precipitate Production	- kg/m^3 of raffinate feed	7.13
	- kg/h	278
	- t/yr	2004.2*
Nickel Production	- kg Ni/yr	601,261*
	- lbs Ni/yr	1,325,553*
Cobalt Production	- kg Co/yr	62,932*
	- lbs Co/yr	138,741*

*based on 323 operating days per year and 93% plant availability.

4.3 Raffinate Pre-Treatment

4.3.1 First-Stage

Raffinate Flow, m^3/h		39.0
H_2O_2 (50%) Addition	- kg/m^3 of raffinate feed	0.64
	- m^3/h	0.021
Retention Time, Pre-Oxidation Pachuca, h		0.5
Fe^{3+} Addition, kg/m^3 of raffinate feed		3.2
Triron (45% $Fe_2(SO_4)_3$) Addition	- kg/m^3 of raffinate feed	26.5
	- t/h	1.033
	- m^3/h	0.66
First-Stage Treatment pH		4.5
Retention Time, First-Stage Treatment Pachuca, h		0.5
Lime (95% CaO) Addition	- kg/m^3 raffinate feed	19.2
	- t/h	0.75
Precipitate	- kg/m^3 raffinate feed	66.3
	- t/h	2.59
Thickener Unit Settling Rate (Conventional), $m^2/t/day$		2.0
Thickener Feed Density, % Solids (w/w)		2 - 4
Thickener Underflow Density, % Solids (w/w)		15*
Flocculant Dosage, g/t of precipitate		40
Flocculant Strength, %		0.05
Flocculant Type		Percol E-10 or equivalent

*design density, actual density may reach 20 % solids (w/w)

4.3.2 Second-Stage

Feed, m^3/h		51.81
Barium Chloride ($BaCl_2 \cdot 2H_2O$) Dosage, mg/L of second-stage feed		29.3
Barium Chloride Solution Strength, g $BaCl_2 \cdot 2H_2O/L$		100
Barium Chloride Solution Flow, L/h		15.2
Retention Time, Radium Removal Pachuca, h		0.5
Fe^{3+} Addition, kg/m^3 of second-stage feed		0.10
Triron (45% $Fe_2(SO_4)_3$)	- kg/m^3 of second-stage feed	0.82
	- t/h	0.043
	- m^3/h	0.03
Second-Stage Treatment pH		5.0
Lime (95% CaO) Addition,	- kg/m^3 second-stage feed	0.476
	- t/h	0.025
Retention Time, Second-Stage Treatment Pachuca, h		0.5
Precipitate	- kg/m^3 raffinate feed	0.92
Precipitate	- t/h	0.036
Reactor-Clarifier Rise Rate, $m^3/h/m^2$		1.92
Reactor-Clarifier Underflow Density, % Solids (w/w)		10*
Reactor-Clarifier Overflow Suspended Solids, ppm		50-70
Flocculant Dosage, ppm		1
Flocculant Strength, %		0.05
Flocculant Type		Percol E-10 or equivalent
Sand Filter Unit Flowrate, $m^3/h/m^2$		15
Backwash Flow, % of feed volume		4

*design density, actual density may reach 15% solids (w/w)

4.3.3 Precipitate Filtration and Wash

Total Precipitate Feed, t/h	2.63
Wash Water pH	3.2
Wash Ratio (t wash water/t precipitate)	4.64
Wash Water flowrate, m^3/h	12.2
Acid (93% H_2SO_4) to Acidified Wash Water Tank, L/h	0.607
Belt Filter Feed Density, % Solids (w/w)	15
Flocculant to Belt Filter Feed, g/t of precipitate	5
Belt Filter Discharge Density, % Solids (w/w)	35
Precipitate Repulp Density, % Solids (w/w)	20
Belt Filter Filtrate to Thickener, m^3/h	22.25
Belt Filter Unit Filtration Rate - kg solids/m^2.h	84
Vacuum, mm Hg	508
Vacuum Air Rate, m^3/h/m^2	146.3
Filter Cake Thickness, mm	15
Filter Media Type	POPR
Wash Efficiency, %	99.6

4.4 Nickel-Cobalt Precipitation

Feed Flowrate, m^3/h		51.78
Reaction Temperature, °C		50
Reaction pH		8.65
Reaction Time, h		0.5
Sodium Carbonate (100% Na_2CO_3) Addition, kg/m^3 PPTN feed		6.11
Sodium Carbonate Solution Strength, gNa_2CO_3/L		100
Sodium Carbonate Solution Flowrate, m^3/h		3.16
Ni-Co Bulk Precipitate	- kg/m^3 of raffinate feed	7.13
	- kg/h	278

Reactor-Clarifier Rise Rate, $m^3/h/m^2$	0.42
Reactor-Clarifier Underflow Density, % Solids (w/w)	12*
Reactor/Clarifier Overflow Suspended Solids, ppm	50-100
Flocculant Dosage, ppm	1
Flocculant Type	Percol E-10 or equivalent
Pressure Filter Design Pressure, kPa (maximum)	690
Pressure Filter Air Blow Rate, $m^3/h/m^2$	18.29
Precipitate Moisture, % H_2O	65
Dry Weight of Precipitate per Chamber, kg	32.3
Pressure Filter Filtration Rate - solids, $kg/h/m^2$	3.75
- pulp, $m^3/h/m^2$	0.029
Area per Chamber, m^2	2.5
Volume per Chamber, m^3	0.034
Number of Chambers	33
Bulk Precipitate Bulk Density, t/m^3	0.96
Pressure Filter Media	POP336HS
Cycle Time, h	4.5

*design density, actual density may reach 15% solids (w/w)

5.0 PROCESS FACILITIES

The following sections provide a physical description of the proposed plant facilities

5.1 General Description

The nickel/cobalt recovery circuit will be built as a separate operation from the uranium circuit. It will be attached to the main mill complex but physically separated and located to ensure that radioactive contamination is not possible. The first stage precipitation circuit will be separated by a barrier from the bulk precipitation circuit, again to ensure maintenance of product purity. In first stage precipitation, the four pachucas will be installed in series in the building with the horizontal belt filter next to them. The belt filter feed tank, the precipitate repulp tank and the belt filter acidified wash water tank would be on the floor below the filter. The first stage pre-treatment thickener and the second stage pre-treatment reactor-clarifier would be outside the building adjacent to the treatment pachucas. Both units would be insulated to maintain solution temperature during the winter.

The second stage clarifier overflow will flow by gravity to a holding tank from where it will be pumped to a pair of sand filters for removal of any colloidal precipitate. The clarified solution will then flow to a second surge tank, the bulk precipitation feed tank. The clear solution will also be used as backwash for the sand filters. Backwash slurry will report to the thickener for recovery of solids.

The solution from the bulk precipitation feed tank will be pumped through a heat exchanger where steam will be used to raise the temperature to 50°C. The heated solution will discharge to a final treatment pachuca where sodium carbonate solution will be added to raise the pH to 8.65. If necessary steam will be added to maintain a constant temperature.

The precipitated nickel/cobalt carbonate will flow by gravity to the bulk precipitate reactor-clarifier. The overflow from the clarifier will be pumped to the second stage effluent treatment circuit in the uranium circuit for disposal. The underflow will be recirculated to maiximize density with the thickened sludge pumped to a holding tank for storage. This slurry will be pumped with positive displacement pumps to a pressure filter where it will be dewatered to approximately 55% solids. The filtrate will be recirculated to the reactor clarifier for recovery of solids. The filter cake will be packed into one tonne tote bags and stored for shipment to the buyer.

5.2 Process Equipment

All pumps, except where otherwise noted, will be centrifugal type, stainless steel for the clear solution streams, rubber lined for slurries. Tankage will be constructed of mild steel with rubber lining or FRP. Tank sizing is listed in the capital cost details presented in Appendix D, it is also included in the detailed process flowsheets in Appendix C.

6.0 CAPITAL COST ESTIMATE

6.1 Summary

The capital cost summary in Table 6-1 provides the estimated cost of installing a nickel/cobalt recovery circuit in conjunction with a milling facility for the Midwest ore. The total estimated cost of $6,544,467, including a 10% contingency, is the estimated cost of a nickel/cobalt recovery facility installed in a separate building adjoining the main process building. Capital cost estimate details prepared by Melis Engineering Ltd. are presented in Appendix D of this report.

6.2 Basis of Estimate

The battery limits for the cost estimate presented in this report are receipt of raffinate solution into the pre-oxidation pachuca to discharge of neutralized solution to the second-stage waste treatment circuit in the main process plant, and storage of nickel/cobalt precipitate in the product load-out area.

The capital cost estimate is based on the following:

- detailed process flowsheets prepared by Melis Engineering Ltd. and included in Appendix C of this report. The flowsheets were developed from Lakefield Research test results (Appendix A) and from Eimco Process Equipment (EPE) liquid-solid separation data derived from testwork by Bill Stone of EPE (Appendix B);
- design criteria as listed in this report;
- cost data from the Midwest Feasibility Study dated July, 1990;
- Melis Enginnering Ltd. file cost data for low-cost items;
- verbal budget quotes for major equipment;
- estimation of installation manhours for individual pieces of equipment;
- construction man-hour rate of $40.00/hour which includes contractor overhead and fee;

- factors adapted from historical data for estimating piping, electrical and instrumentation costs for individual areas of the process;
- allowance for additional cost of reagents and services with the supply assumed to come from the main process plant.

The following have been included in the capital costs estimate:

- process equipment as shown on the detailed flowsheets;
- mechanical installation;
- field materials factored from equipment costs;
- process piping factored from installed mechanical cost;
- electrical pipin factored from installed mechanical cost;
- instrumentation piping factored from installed mechanical cost;
- freight either separately estimated for large loads or as a percentage of equipment costs;
- provincial sales tax at 8%;
- building costs complete with internal services;
- concrete;
- internal steelwork and walls;
- control room with an allowance for additional computer control equipment required for the nickel/cobalt recovery circuit;
- product load-out facility with product storage on-site;
- construction indirects;
- engineering and procurement;
- construction management;
- owner's costs; and
- contingency.

6.3 Net Capital Cost

Table 6.1 on the following page provides a summary of the capital costs by area. A detailed breakdown of costs is included as Appendix D of this report. The total capital cost is estimated at $6.54 million. Of the direct costs, excluding the building, the costs related to first and second stage effluent treatment make up 35.67 % of the total. This cost replaces much of the expenditure in the uranium effluent treatment plant. The valid incremental cost is therefore 64.33 % of the total capital cost. The net capital cost is therefore estimated at $4,209,848.

Table 6.1: Capital Cost Estimate Summary

	Area	$
Direct Costs	First Stage Pre-Treatment	850,325
	First Stage Precipitate Filtration	1,148,451
	Second Stage Pre-Treatment	575,841
	Nickel/Cobalt Bulk Precipitation	952,850
	Reagents and Services	470,400
	Building	876,600
Total Direct Costs		**4,874,467**
Indirect Costs	Engineering Procurement, Construction Management	500,000
	Camp Costs	125,000
	Turnaround	50,000
	Mobilization and Demobilization	50,000
	Construction Equipment and Small Tools	100,000
	Owner's Cost	250,000
Total Indirect Costs		**1,075,000**
Total Direct and Indirect Costs		**5,949,467**
Contingency		**595,000**
TOTAL ESTIMATED CAPITAL COSTS		**6,544,467**

7.0 OPERATING COST ESTIMATE

7.1 Summary

Table 7.1 below contains a summary of the operating costs for the nickel/cobalt recovery circuit. The estimated annual operating cost for the plant is slightly more than $1.4 million. Since it is probable that miscellaneous costs will increase this cost slightly, a figure of $1.5 million is used in estimating the payback period.

Table 7.1: Operating Cost Detail

ITEM	ANNUAL CONSUMPTION	UNIT COST ($)	ANNUAL COST ($,000)
Sodium Carbonate	2281 t	320/t	730
Lime (replaced)	1269 t	190/t	(241)
Hydrogen Peroxide	90 t	1272/t	114
Flocculant	0.5t	3000/t	2
Sulphuric Acid	8t	176/t	1
Lime (neutralization)	5t	190/t	1
Steam	11,212t	30/t	336
Power	901,890 kwh	0.10/kwh	90
Heating			3
Maintenance			195
Labour	4 men	50,000/man.year	200
TOTAL			1431

7.2 Basis of Calculation

The operating cost for the nickel/cobalt facility is calculated on the assumption that the plant essentially replaces the first stage of effluent treatment in the uranium circuit. The only reagent costs which are included are for items which are incremental to those already planned for effluent treatment. No charge is included for ferric sulphate or for barium chloride. The only lime charge is for the limited quantity necessary to neutralize the acid used to wash the first stage precipitate. A credit is applied to take into account the effluent treatment lime which would be replaced by sodium carbonate. Flocculant is charged for use only in the bulk precipitation reactor-clarifier and in the belt filter feed distributor, since the other thickeners replace the first stage effluent treatment unit. Sodium carbonate and hydrogen peroxide are presented at full cost since they would not be used in the uranium effluent treatment circuit.

Power costs are estimated on the basis of the electricity consumed in the bulk precipitation and filtration areas alone. An allowance for heating costs is estimated using the size of the planned building relative to that of the uranium circuit. Steam is estimated using the amount of heat required to raise the temperature of the bulk precipitation feed volume from 30°C to 50°C.

Labour costs are based upon the need for four additional employees to operate the circuit. Maintenance costs are estimated at 3 % of the total equipment costs. Included in the maintenance total is maintenance and service labour at 50% of operating labour cost.

8.0 POTENTIAL REVENUES

8.1 Revenue from Production

Potential revenue from the process is based upon figures previously supplied by Falconbridge Limited combined with more recent metal price quotations. Unless otherwise noted, all prices are presented in US dollars, all unit weights are in pounds.

Nickel Price:	3.30
Return from Smelter:	80%
Refining Charge:	0.65
Net Nickel Price:	1.99
Estimated Nickel Production:	1,325,553
Nickel Revenue:	2,637,850
Cobalt Price:	20.00
Return from Smelter:	65%
Refining Charge:	1.50
Net Cobalt Price:	11.50
Estimated Cobalt Production:	138,741
Cobalt Revenue:	1,595,522
Revenue:	4,233,372
Smelter Charges:	190/t
Transportation Cost:	160/t
Concentrate Production (t):	2004.2
Smelter and Transport Charges:	701,470
Final Net Revenue:	3,531,902
Net Revenue (Canadian dollars):	4,255,300

8.2 Annual Profit and Estimated Payback Period

Overall revenue is estimated to be $4.25 million per year. With annual operating costs of

$1.5 million, annual profit is expected to be $2.75 million. With a net capital expenditure of $4.21 million, the payback period is calculated to be approximately 1.5 years. The one area remaining where a potential exists for significant cost savings both in capital and operating expenditures, is the use of lime for nickel/cobalt precipitation at ambient temperature instead of sodium carbonate at elevated temperatures.

It has been recommended that the use of lime as a precipitant be investigated further. Initial testwork indicated a significant difference in concentrate quality between carbonate and hydroxide precipitates. The larger scale test program, however, did not indicate a significant difference. If product quality with lime is the same as with carbonate then there is a potential saving of $824,000 in annual operating costs. Capital cost savings could be approximately $225,000.

It may be that, to provide complete assurance that the product is free of radioactive contamination, a third stage of pre-treatment should be installed if lime is used instead of carbonate. This extra stage would result in a capital expenditure of approximately $700,000, a net increase of $475,000. Additional reagent consumption would be negligible however, so the large reagent savings ($824,000) would pay back the increased capital in approximately 7 months. Net profit would then increase to $3.57 million annually if lime precipitation of nickel/cobalt was satisfactory. This option should be closely investigated prior to detailed engineering.

Appendix A

LAKEFIELD RESEARCH

Progress Reports 1 & 2

An Investigation of

THE RECOVERY OF NICKEL AND COBALT

from Midwest Uranium Raffinate

submitted by

MIDWEST JOINT VENTURES

Progress Report No. 1

Project No. L.R. 4234

NOTE:

This report refers to the samples as received.

The practice of this Company in issuing reports of this nature is to require the recipient not to publish the report or any part thereof without the written consent of Lakefield Research.

LAKEFIELD RESEARCH
A DIVISION OF FALCONBRIDGE LIMITED
April 2nd, 1992

ABSTRACT

A hydrometallurgical test program was conducted on a Midwest uranium raffinate sample to evaluate various treatment options for the recovery of cobalt and nickel. The program included raffinate pretreatment tests for the precipitation of impurities, cobalt/nickel precipitation tests on a purified raffinate solution, solvent extraction tests for the selective recovery of cobalt from nickel contained in the purified raffinate solution, and finally, cobalt and nickel carbonate precipitation tests for product evaluation.

The test program successfully demonstrated that cobalt and nickel can be recovered from uranium raffinate. The raffinate pretreatment tests successfully developed a two stage precipitation process to produce a purified raffinate solution essentially free of aluminum, arsenic, iron, and radium. The purified raffinate solution was determined to be amenable as feed for cobalt/nickel precipitation with sodium carbonate precipitant or solvent extraction with Cyanex 272 extractant. All cobalt and nickel precipitates were determined to be essentially free of aluminum, arsenic, iron, uranium, and radium. The precipitates did however contain calcium and magnesium.

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INTRODUCTION

The processing of Midwest uranium ore will involve autoclave leaching in a sulphuric acid solution under oxidizing conditions. This treatment will dissolve 99% of the uranium, 80% of the arsenic, 80% of the cobalt and 70% of the nickel contained in the ore feed. The uranium will be selectively recovered by solvent extraction and the waste raffinate would normally be neutralized in an effluent treatment process and discarded to the tailings.

The quantity of cobalt and nickel in the raffinate solution is substantial, and is considered to be a significant economic benefit to the Midwest project. However, it would be necessary to remove impurities such as aluminum, arsenic, iron and radium from cobalt and nickel contained in the raffinate prior to the production of a saleable nickel /cobalt product.

This report documents the hydrometallurgical test program conducted during the period from January 13 to March 10, 1992 on a uranium raffinate sample. The test program evaluated impurity removal by precipitation, cobalt-nickel precipitation and the separation of cobalt from nickel by solvent extraction.

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SUMMARY

1. Preparation of Uranium Raffinate

A 170 L raffinate sample was prepared from diluted autoclave discharge liquor (generated during Test No. 18, Progress Report No. 2, Project No. LR 3915). Analyses on the diluted autoclave discharge liquor are presented in Table 1.

Table 1: Analyses of Diluted Autoclave Leach Liquor

Element	Analyses (mg/L)
U	2780
As	5640
Ni	5340
Co	540

The raffinate was prepared by three repeat contacts (at an O/A ratio of 1/1) with freshly stripped organic containing 5% v/v Alamine 336 to extract uranium. A flowsheet illustrating the procedure for the preparation of the raffinate sample is shown in Figure 1.

The raffinate sample was analyzed for elements as shown in Table 2.

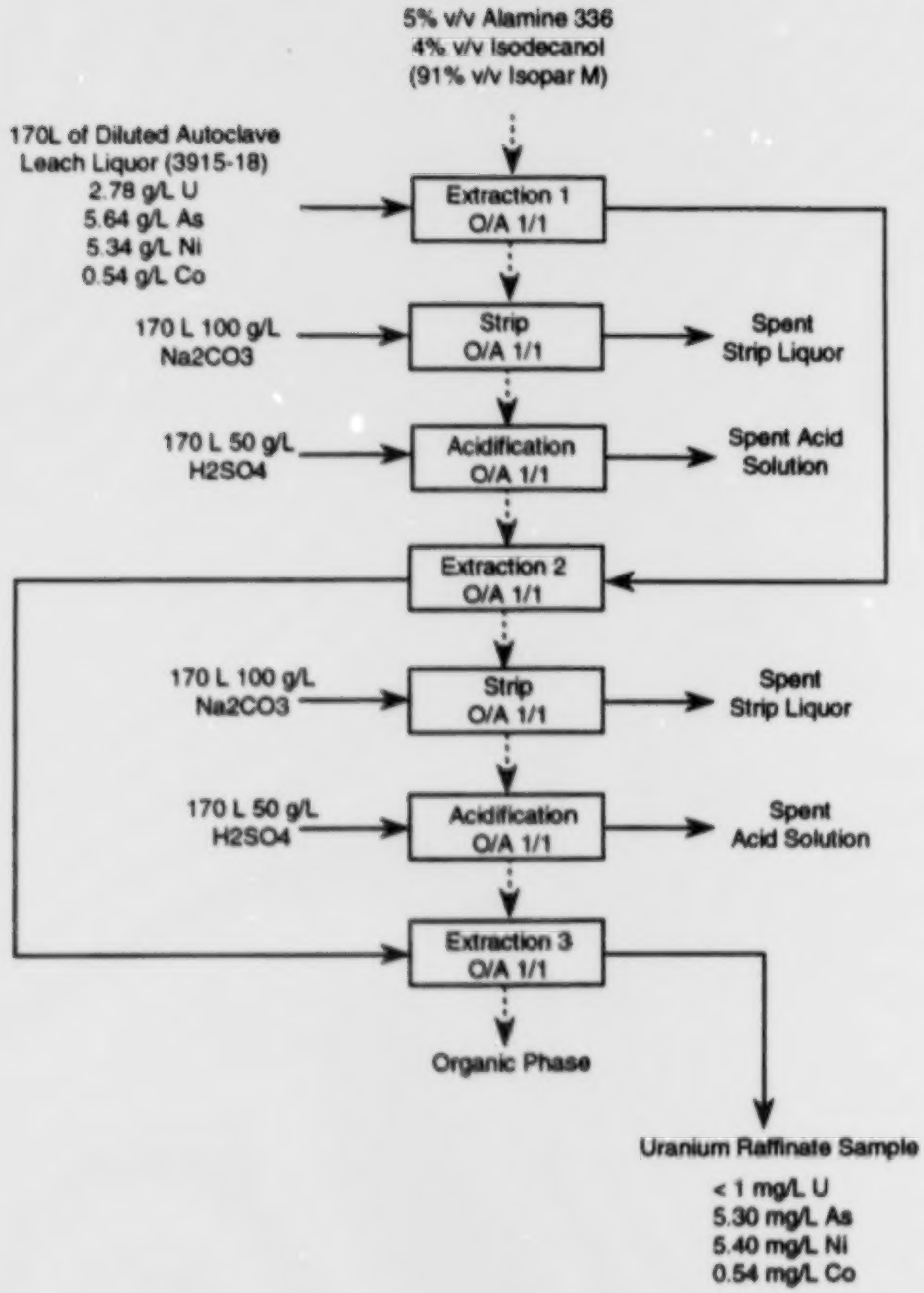

5% v/v Alamine 336
4% v/v Isodecanol
(91% v/v Isopar M)
170L of Diluted Autoclave
Leach Liquor (3915-18)
2.78 g/L U
5.64 g/L As
5.34 g/L Ni
0.54 g/L Co
Extraction 1
O/A 1/1
170 L 100 g/L
Na2CO3
Strip
O/A 1/1
Spent
Strip Liquor
170 L 50 g/L
H2SO4
Acidification
O/A 1/1
Spent Acid
Solution
Extraction 2
O/A 1/1
170 L 100 g/L
Na2CO3
Strip
O/A 1/1
Spent
Strip Liquor
170 L 50 g/L
H2SO4
Acidification
O/A 1/1
Spent
Acid Solution
Extraction 3
O/A 1/1
Organic Phase
Uranium Raffinate Sample
< 1 mg/L U
5.30 mg/L As
5.40 mg/L Ni
0.54 mg/L Co

Figure 1: Flowsheet Detailing the Preparation of Uranium Raffinate

Table 2: Analyses of Uranium Raffinate

Element	Analyses (mg/L)
Al	2100
As	5300
Ba	<0.05
Be	0.84
Ca	120
Cd	<0.10
Co	538
Cr	2.8
Cu	0.69
Fe	69
Mg	590
Mn	9.7
Mo	3.1
Na	13
Ni	5400
P	5.6
Pb	4.7
S	10000
Sb	<0.82
Se	3.3
Si	22
Sn	<0.20
Te	<0.62
U	<1.0
Zn	8.0
Ra_{226}	55 Bq/L
pH	1.12
emf	478 mV
H_2SO_4	12.0 g/L

The analyses in Table 2 show that the sample was representative of a typical raffinate that would be expected in the actual process.

2. Raffinate Pretreatment Tests

Raffinate pretreatment tests were conducted to define the conditions for efficient removal of impurities such as aluminum, arsenic, iron and radium, with minimum losses of cobalt and nickel. The removal of impurities from the raffinate would provide a solution more amenable to a subsequent bulk precipitation or solvent extraction separation process for the recovery of cobalt and nickel.

2.1 1st Stage Precipitation Tests

Four bench scale precipitation tests were conducted on 7L batches of uranium raffinate. In all four tests, the raffinate was neutralized with $Ca(OH)_2$ and samples were removed for analyses at pH 3, 4, 5 and 6. Test No. 1 was a baseline test without any addition of barium chloride or ferric ion. Test No. 2 evaluated the effect of barium chloride at an addition of 25 mg/L $BaCl_2 \cdot 2H_2O$. Test No. 3 and 4 studied the effect of ferric ion addition at an Fe^{+3}/As molar ratio of 0.5/1 and 1/1 respectively. Test details are provided in Appendix A and the results are summarized in Table 3.

Table 3: Summary of 1st Stage Precipitation Tests

Test No.	Terminal pH	$BaCl_2$ Addition mg/L	$Fe_2(SO_4)_3$ Addition Fe^{+3}/As Molar Ratio	Percentage Precipitated					
				Al %	As %	Co %	Fe %	Ni %	Ra_{226} %
1	3.0	0	0	12.2	15.4	5.3	51.5	3.4	52.4
	4.0	0	0	97.1	87.3	16.0	98.5	14.2	95.1
	5.0	0	0	99.9	88.3	20.0	99.7	17.0	98.1
	6.0	0	0	100.0	98.8	25.5	99.9	19.8	99.5
2	3.0	25	0	10.7	14.0	1.4	51.1	2.7	95.1
	4.0	25	0	94.7	84.5	8.2	98.6	1.1	99.0
	5.0	25	0	99.8	88.2	14.1	99.6	8.6	99.7
	6.0	25	0	100.0	90.4	22.5	99.9	18.4	99.9
3	3.0	0	0.5	16.0	77.1	6.7	97.3	2.6	90.6
	4.0	0	0.5	54.4	86.1	9.0	97.4	1.9	93.6
	5.0	0	0.5	99.6	92.6	14.2	98.6	9.1	97.4
	6.0	0	0.5	99.9	96.5	31.6	99.8	28.8	99.5
4	3.0	0	1.0	3.9	90.1	5.7	96.2	2.6	77.1
	4.0	0	1.0	25.3	91.8	9.2	97.1	4.3	88.3
	5.0	0	1.0	99.6	97.1	20.0	98.5	12.0	95.7
	6.0	0	1.0	100.0	99.0	38.2	99.9	30.4	98.9

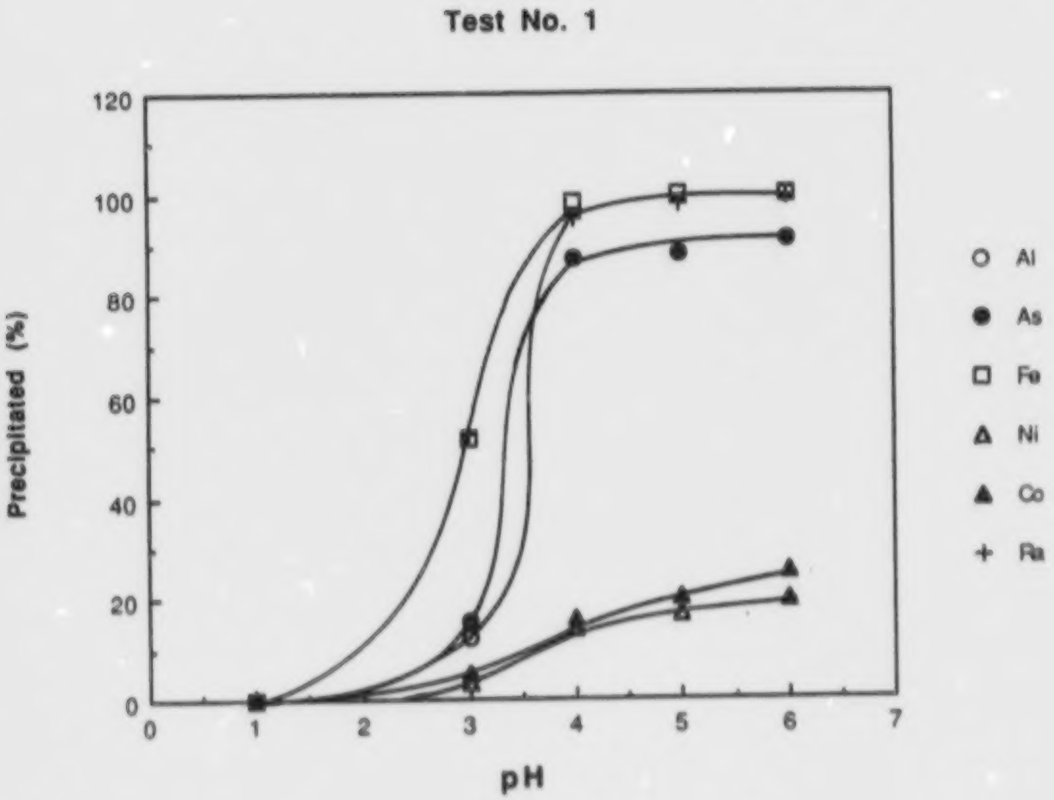


Figure 2: The percent precipitated by $Ca(OH)_2$ neutralization as a function of pH

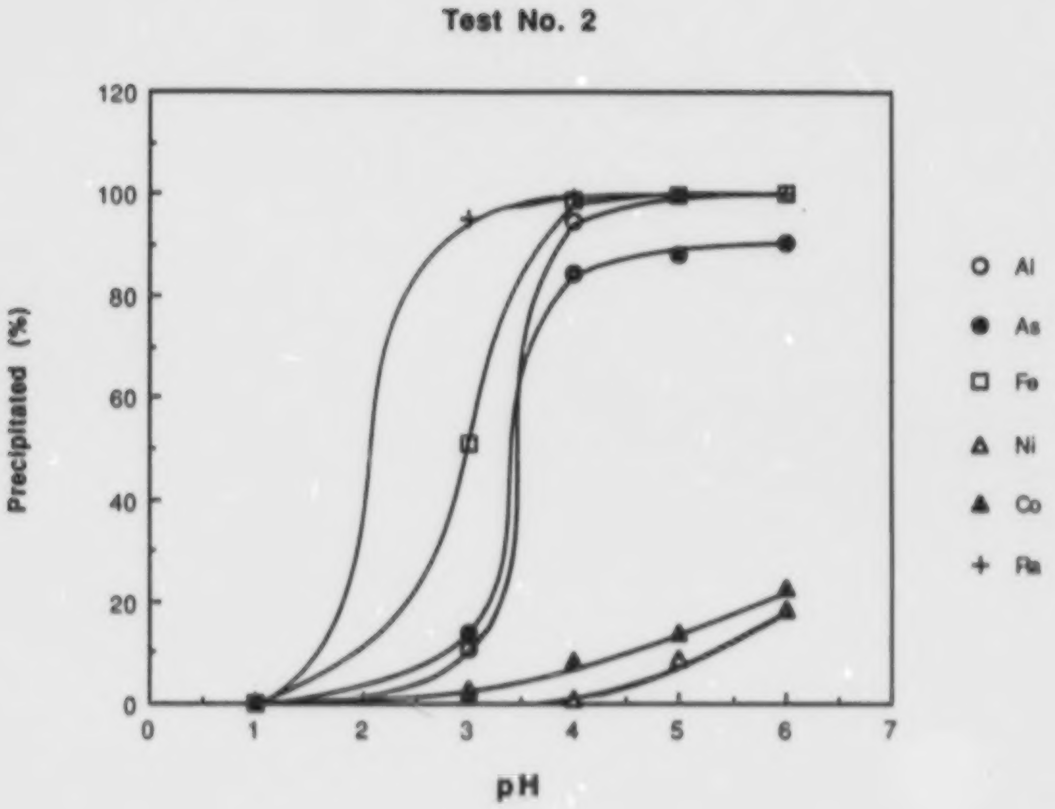


Figure 3: The percent precipitated by $Ca(OH)_2$ neutralization with 25 mg/L $BaCl_2 \cdot 2H_2O$

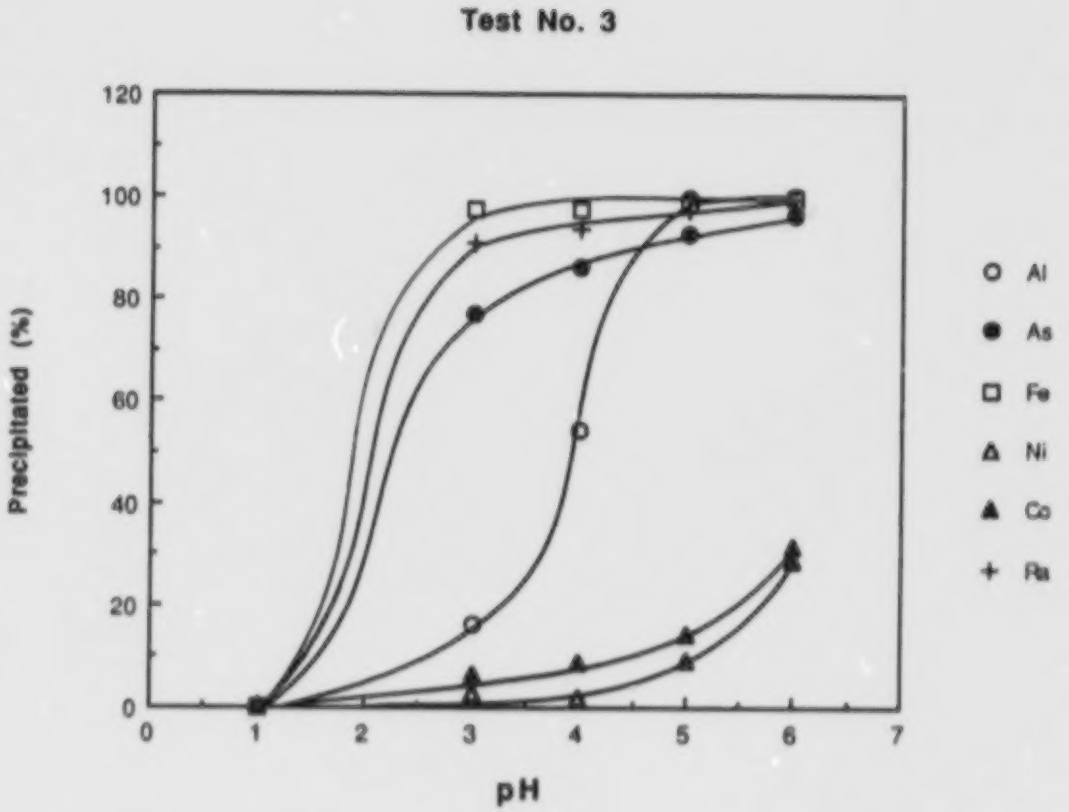


Figure 4: The percent precipitated by $Ca(OH)_2$ neutralization with 0.5/1 Fe^{+3}/As molar ratio as a function of pH

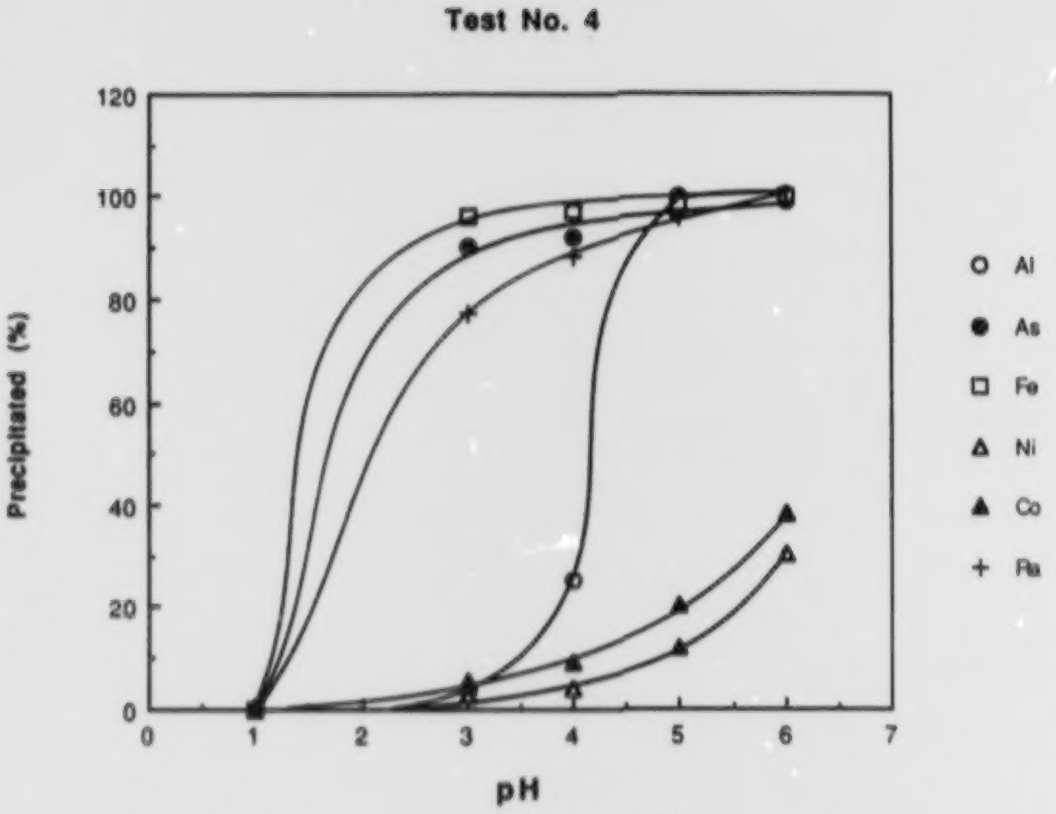


Figure 5: The percent precipitated by $Ca(OH)_2$ neutralization with 1/1 Fe^{+3}/As molar ratio as a function of pH

Figure 2 shows the effect of pH on the precipitation of Al, As, Co, Fe, Ni and Ra_{226} from the uranium raffinate sample using $Ca(OH)_2$. The results in Figure 2 show good separation of impurities (Al, As, Fe, Ra_{226}) from Co and Ni between pH 4 to 6. At pH 5, virtually 100% of the Al and Fe was precipitated with 88% of the As. The data also indicated that 17 to 20% of the nickel and cobalt precipitated at pH 5.

The data in Figure 3 show the effects of pH on the precipitation of impurities with the addition of barium chloride. The results in Figure 3 shows a similar trend for the precipitation of impurities as compared to Figure 2 except for more efficient removal of radium. Of particular importance, the results indicated that in the presence of chloride, the solubility of cobalt and nickel was enhanced. The effect was demonstrated at pH 5 where only 14.1% and 8.6% of the cobalt and nickel precipitated.

Figures 4 and 5 compared the effects of ferric ion addition at 0.5/1 and 1/1 Fe^{+3}/As molar ratios. The results show that the addition of ferric ion slightly improved the precipitation of arsenic at pH 4 to 6. However, substantial amounts of iron remained in solution with cobalt and nickel.

The iron remaining in solution was probably in the ferrous state, as ferric iron is insoluble in the 4 to 6 pH range. The addition of hydrogen peroxide to the raffinate prior to neutralization should prevent the formation of ferrous iron and also keep the arsenic in the oxidized arsenate state.

2.2 Recovery of Co and Ni from 1st Stage Precipitate

To determine the efficiency of dilute acid for solubilizing or washing out cobalt and nickel contained in the 1st stage precipitate, repulp tests were conducted. A sample of fresh, wet, 1st stage precipitate, prepared as detailed in Test No. 4A, was repulped in dilute sulphuric acid solutions at pH 2.0, 2.5, 3.0 and 3.5. After a 30 minute period, the samples were filtered, washed and the impurities solubilized with cobalt and nickelwere determined. The results are shown graphically in Figure 6 and indicate a repulp pH of 3.0 provided 82 and 72% recovery of cobalt and nickel with minimum dissolution of impurities.

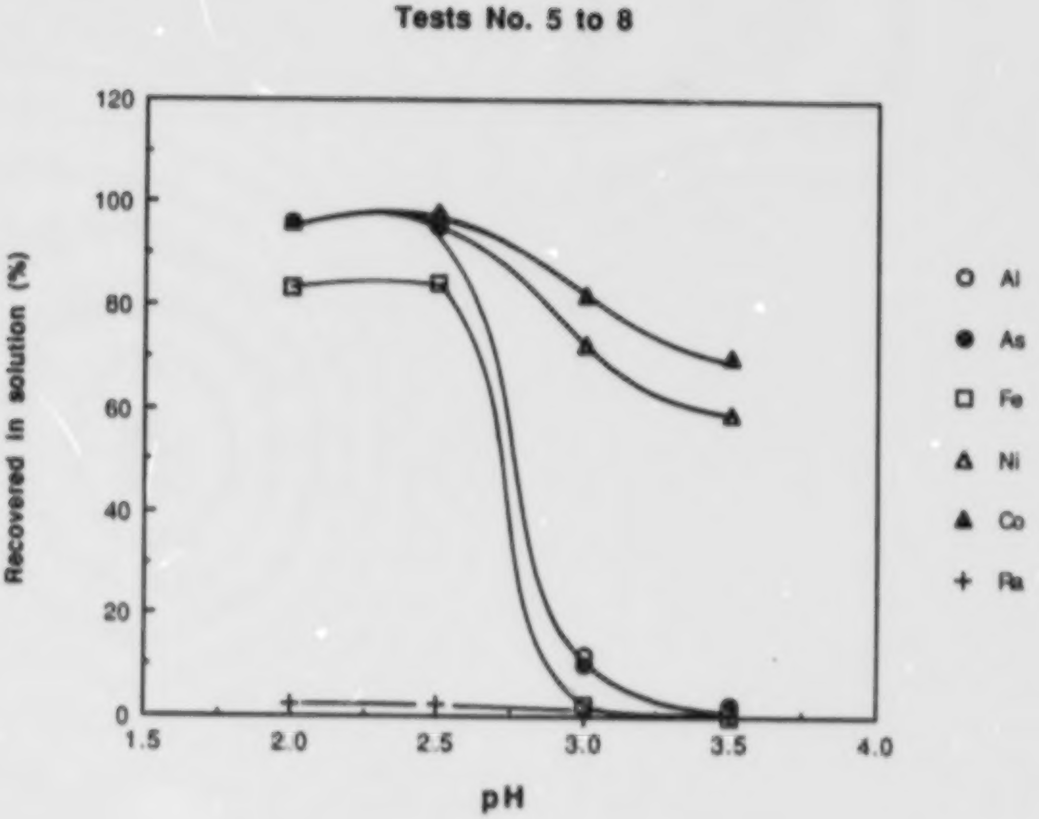


Figure 6: The effect of repulp pH on the solubilization of Co, Ni and impurities contained in the 1st stage precipitate

Table 4: Summary of Repulp Tests for the Recovery of Co and Ni from 1st Stage Precipitate.

Test No.	Repulp pH	Recovered in Solution (%)					
		Al	As	Co	Fe	Ni	Ra_{226}
5	2.0	96	96	96	83	96	2.2
6	2.5	97	95	98	84	97	2.5
7	3.0	12	10	82	2.5	72	0.1
8	3.5	2.0	2.4	70	0.1	59	0.0

2.3 2nd Stage Precipitation

Second stage precipitation tests were conducted at pH 4 to study the effect of various barium chloride additions and ferric ion to arsenic ratios. The results are summarized in Tables 5 and 6. Test details are provided in Appendix A, Tests No. 9 to 16.

Table 5: The Effect of Barium Chloride Addition During 2nd Stage Precipitation

Test No.	pH	$BaCl_2 \cdot 2H_2O$ mg/L	Precipitated (%) *					
			Al	As	Co	Fe	Ni	Ra_{226}
9	4.0	2	0.0	4.6	4.7	0.0	4.7	0.0
10	4.0	10	0.0	2.5	2.4	0.0	2.5	>75**
11	4.0	25	0.0	3.6	3.0	0.0	3.8	>75**
12	4.0	50	0.0	1.9	0.7	0.0	1.4	>75**

* Calculated on solution analyses

** Result were calculated based on the filtrate analyses at the detection limit of<0.03 Bq/L

The results show that at least 10 mg/L $BaCl_2 \cdot 2H_2O$ was required to complete the precipitation of radium.

Table 6: The effect of Fe^{+3}/As Molar Ratio During 2nd Stage Precipitation

Test No.	pH	Fe^{+3}/As molar ratio	Precipitated (%) Al	As	Co	Fe	Ni
13	4.0	0.25/1	0.0	18	0.0	85	0.0
14	4.0	0.5/1	0.0	35	0.0	82	0.0
15	4.0	1/1	0.0	52	0.0	85	0.0
16	4.0	5/1	0.0	96	0.0	86	0.0

The results show that during second stage precipitation a high Fe^{+3}/As molar ratio of 5/1 was required to precipitate 96% of arsenic that remained in solution from first stage treatment.

Only 82 to 86% of the iron was precipitated suggesting that the iron remaining in solution was in the ferrous state. The addition of hydrogen peroxide during second stage precipitation should improve the iron precipitation efficiency.

2.4 Precipitation of Impurities from an Oxidized Raffinate Solution

Two 1st stage precipitation tests were conducted at pH 5 and pH 6 on a sample of oxidized raffinate. The raffinate sample was oxidized by hydrogen peroxide to a terminal emf of 603 mV. Barium chloride was added at an addition of 25 mg/L and ferric ion was added at an Fe^{+3}/As molar ratio of 1/1. In Test No. 17 the solution was neutralized with $Ca(OH)_2$ to pH 5 and Test No. 18 to pH 6. Precipitates from both tests were repulped in pH 3.5 H_2SO_4 to determine the recovery of precipitated metals. The results are presented in Table 7. Test details are provided in Appendix A.

Table 7: Results from Precipitation Tests on Oxidized Raffinate.

Test No.	Neutralization pH	Precipitated (%)					Overall Recovery in Solution (%)*				
		Al	As	Co	Fe	Ni	Al	As	Co	Fe	Ni
17	5.0	99.7	100	5.3	99.1	0.9	52	0.3	99	1.2	100
18	6.0	100	100	43	100	32	37	0.2	96	0.2	98

* The precipitate was repulped in pH 3.5 H_2SO_4 to solubilize precipitated Co and Ni.

The results demonstrate the importance of pre-oxidation of the raffinate prior to 1st stage precipitation. At pH 5, 99% of the iron was precipitated and at pH 6, 100% was precipitated. Complete precipitation of arsenic also occurred from the pre-oxidized raffinate. Repulping the precipitates in pH 3.5 H_2SO_4 acid produced an overall recovery for Co and Ni between 96 to 100%.

2.5 Preparation of Purified Raffinate Solution

A test was conducted as shown in Figure 7 on 50 L of uranium raffinate to produce a purified raffinate solution for bulk Co-Ni precipitation and solvent extraction testwork. Test details are provided in Appendix A, Test No. 19.

The procedure did not include repulping of the 1st stage precipitate for the recovery of Co and Ni. The overall distribution of metals are presented in Table 8.

Table 8: The Distribution of Metals Throughout Test No. 19

Product	Distribution of Metals (%)					
	Al	As	Co	Fe	Ni	Ra226
Purified Raffinate Solution	0.3	0.8	79.0	0.0	80.8	0.0
Precipitates	99.7	99.2	21.0	100.0	19.2	100.0

Repulp of the precipitate in pH 3 to 3.5 H_2SO_4 would improve the recovery of Co and Ni.

Test No. 19

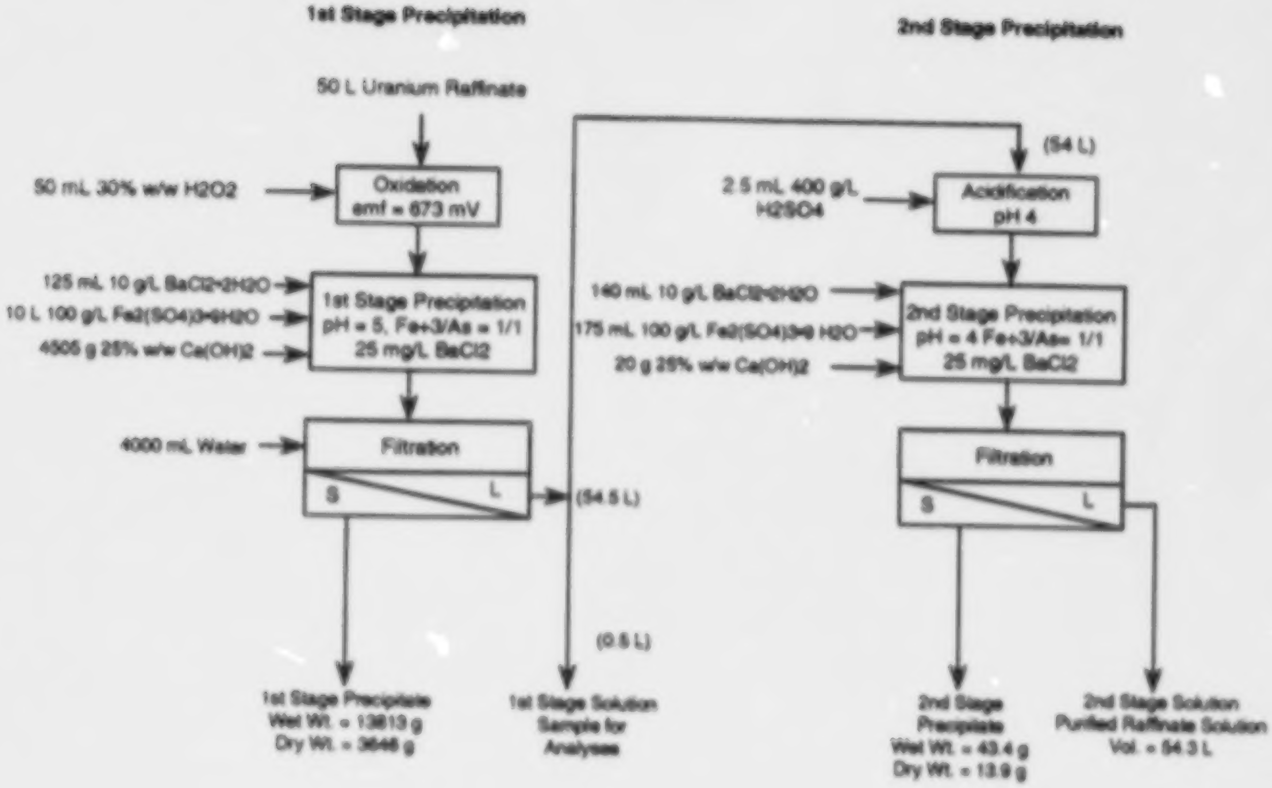

1st Stage Precipitation
50 L Uranium Raffinate
50 mL 30% w/w H2O2
Oxidation
emf = 673 mV
125 mL 10 g/L BaCl2•2H2O
10 L 100 g/L Fe2(SO4)3•6H2O
4505 g 25% w/w Ca(OH)2
1st Stage Precipitation
pH = 5, Fe+3/As = 1/1
25 mg/L BaCl2
4000 mL Water
Filtration
S
L
(54.5 L)
(0.5 L)
1st Stage Precipitate
Wet Wt. = 13813 g
Dry Wt. = 3646 g
1st Stage Solution
Sample for
Analyses
2nd Stage Precipitation
(54 L)
2.5 mL 400 g/L
H2SO4
Acidification
pH 4
140 mL 10 g/L BaCl2•2H2O
175 mL 100 g/L Fe2(SO4)3•6 H2O
20 g 25% w/w Ca(OH)2
2nd Stage Precipitation
pH = 4 Fe+3/As= 1/1
25 mg/L BaCl2
Filtration
S
L
2nd Stage
Precipitate
Wet Wt. = 43.4 g
Dry Wt. = 13.9 g
2nd Stage Solution
Purified Raffinate Solution
Vol. = 54.3 L

Figure 7: Flowsheet Detailing Procedure for Preparation of Purified Raffinate Solution

A portion of the 2nd stage solution was treated by a 3rd stage precipitation for further reduction of arsenic. The 3rd stage precipitation included the addition of hydrogen peroxide to increase the emf from 464 mV to 500 mV. A small amount of hydrogen peroxide was also added to the ferric sulphate solution to adjust the emf to 745 mV. Ferric sulphate was added at a Fe^{+3}/As molar ratio of 4/1.

Test details are provided in Appendix A, Test No. 19a and the analyses on the 1st, 2nd and 3rd stage solutions are given in Table 9.

Summary

Table 9: Analyses of 1st Stage, 2nd Stage and 3rd Stage Solutions

Element	Solution Analyses (mg/L) 1st Stage Solution	2nd Stage Solution	3rd Stage
Al	4.7	5.6	5.86
As	85	37	5.96
Ba	<0.05	<0.05	<0.05
Be	<0.01	<0.01	<0.01
Ca	430	520	520
Cd	<0.50	<0.10	<0.10
Co	380	390	379
Cr	<0.05	<0.05	<0.05
Cu	0.11	3.9	3.9
Fe	0.10	0.99	0.54
Mg	510	520	520
Mn	9.98	15	15
Mo	<0.20	<0.20	<0.20
Na	11	14	14
Ni	3990	4000	3900
P	<0.20	<0.20	<0.20
Pb	<1.0	1.7	1.7
S	3030	3500	3500
Sb	<0.10	<0.70	<0.70
Se	<0.50	<0.50	<0.50
Si	11	12	12
Sn	<0.20	<0.20	<0.20
Te	<0.10	<0.10	<0.10
Zn	8.2	9.4	9.4
Ra_{226} (Bq/L)	-	0.04	-

The 2nd stage solution was used as feed to the precipitation tests as outlined in Section 3 and the 3rd stage solution was used as feed to solvent extraction tests as detailed in Section 4.

2.6 Conceptual Raffinate Pretreatment Flowsheet

A conceptual flowsheet for the precipitation of impurities from the uranium raffinate was prepared as shown in Figure 8. In the conceptual process, the raffinate would first be treated with hydrogen peroxide to oxidize any reducing material, such as organics from the uranium solvent extraction circuit, and to ensure that all of the iron and arsenic are in the oxidized states. A key feature of the conceptual flowsheet is a two stage precipitation for the removal of impurities. This would ensure that the cobalt/nickel product(s) would not become contaminated with impurities in the event of an upstream processing problem or large variations in ore feed.

In the first stage of precipitation, that raffinate would be neutralized with lime to a pH of 4.5 to 5.0. Ferric sulphate would also be added to the first stage precipitation, to precipitate arsenic as a stable ferric arsenate. The addition of ferric iron would be at least 1/1 Fe^{+3}/As molar ratio, however, higher additions of ferric iron may be required to completely stabilize the ferric arsenate compound.

Cobalt and nickel precipitated during the first stage precipitation would be recovered by washing the precipitate with pH 3.0 to 3.5 sulphuric acid. Cobalt and nickel would be solubilized by the dilute acid along with lesser amounts of impurities. The dilute acid wash solution would be combined with the treated first stage solution and advanced to second stage precipitation.

The second stage precipitation would include radium precipitation and residual precipitation. Radium precipitation would be accomplished by the addition of barium chloride at pH 4.0 to co-precipitate radium with barium sulphate. Residual precipitation would completely precipitate remaining impurities left in solution. Ferric sulphate would be added at an addition of at least 4/1 Fe^{+3}/As molar ratio and the solution would be neutralized to pH 5.5 to 6.0 with lime. The relatively high pH would be required to completely precipitate impurities such as aluminum and zinc. Unfortunately, up to 30% of the cobalt and nickel would be precipitated. The resulting second stage precipitate would be recycled to the front end of the pretreatment circuit to recover precipitated cobalt and nickel. The precipitated metal hydrates would help to consume some of the acid contained in the raffinate.

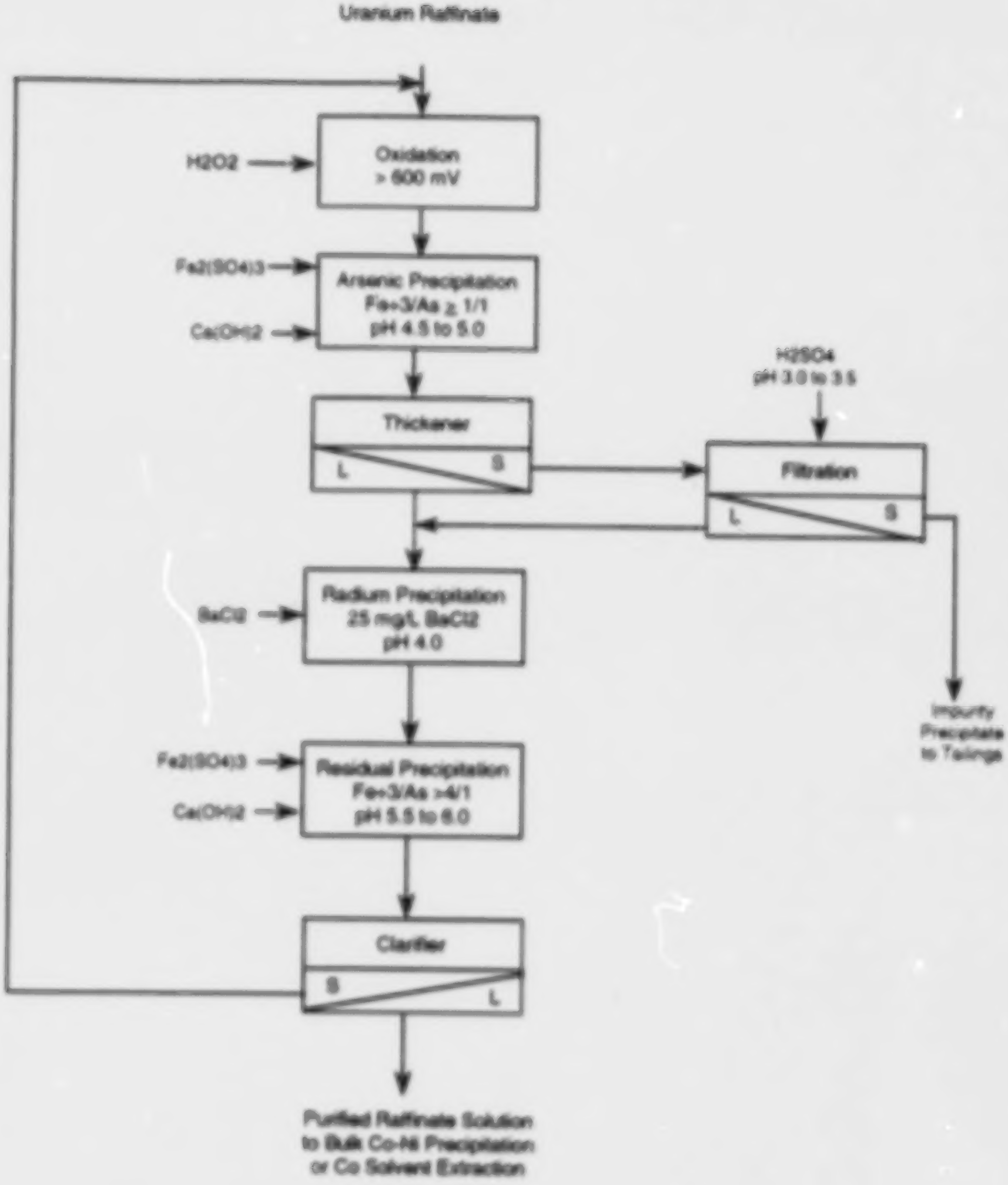

Uranium Raffinate
H2O2
Oxidation
> 600 mV
Fe2(SO4)3
Arsenic Precipitation
Fe+3/As ≥ 1/1
pH 4.5 to 5.0
Ca(OH)2
H2SO4
pH 3.0 to 3.5
Thickener
L
S
Filtration
L
S
BaCl2
Radium Precipitation
25 mg/L BaCl2
pH 4.0
Impurity
Precipitate
to Tailings
Fe2(SO4)3
Residual Precipitation
Fe+3/As >4/1
pH 5.5 to 6.0
Ca(OH)2
Clarifier
S
L
Purified Raffinate Solution
to Bulk Co-Ni Precipitation
or Co Solvent Extraction

Figure 8: Conceptual flowsheet for the pretreatment of uranium raffinate

3. Precipitation of Co-Ni from Purified Raffinate

Four precipitation tests were conducted to co-precipitate cobalt and nickel from the 2nd stage purified raffinate solution. The tests evaluated sodium hydrogen sulphide, calcium hydroxide and sodium carbonate precipitants.

Test No. 20 was conducted with a stoichiometric addition of NaHS. This precipitant was not very efficient as less than 50% of the Co and Ni were precipitated. An excess of NaHS would probably be required to improve the precipitation efficiency for Co and Ni. This excess would mean that further downstream treatment would be required for the removal of sulphide from the barren solution.

Test No. 21 was conducted by slowly neutralizing the test solution to pH 10.5 with a 25% w/w $Ca(OH)_2$ slurry. The results showed complete precipitation of Co and Ni and almost complete precipitation of As as well. The precipitate was granular (not slimy) and filtered very well. However the precipitate was at least 50% heavier than the other precipitates which would increase shipping costs. The precipitate also contained a substantial amount of calcium at 16%.

Test No. 22 was conducted by slowly neutralizing the test solution to pH 8.67 with a 200 g/L Na_2CO_3 solution. Almost complete precipitation of Co and Ni occurred with the best selectivity against As. The precipitate was slimy and many cracks were observed during filtration. The filtrate was milky, probably containing colloidal precipitate which easily dissolved when the filtrate was acidified.

Test No. 23 was conducted similarly to Test No. 22 except at 50°C and a different feed solution. The higher temperature improved the filtration characteristics producing a filtrate that was clear and colourless. The precipitation efficiencies for Co and Ni were very good at 99.6 to 99.7%.

The results and precipitate analyses are summarized in Table 10 and test details are provided in Appendix B.

Table 10: Summary of Cobalt-Nickel Precipitation Tests

Element	Analyses (%)			
	Co-Ni Sulphide (Test No. 20)	Co-Ni Hydroxide (Test No. 21)	Co-Ni Carbonate (Test No. 22)	Co-Ni Carbonate (Test No. 23)
Al	0.05	0.07	0.09	0.08
As	0.66	0.27	0.29	0.04
Ca	0.04	16	4.1	4.8
Co	3.6	2.0	4.2	3.46
Fe	0.03	0.03	0.03	0.10
Mg	0.04	1.8	0.68	1.6
Ni	38.8	20.8	41.8	36.1
U	0.00033	0.00017	0.0002	0.00033
Zn	0.1	0.06	0.12	0.13
Ra_{226} (Bq/g)	0.05	0.05	0.01	0.04
Wet wt. (g)	35.0	101.4	81.1	110.7
Dry wt. (g)	7.3	30.7	13.7	15.5
Co precipitated (%)	49.2	99.9	98.3	99.7
Ni precipitated (%)	48.1	100.0	98.2	99.6

4. Solvent Extraction

The purified raffinate solution (3rd stage solution) was used as SX feed for the solvent extraction test program. The program evaluated phosphinic and phosphonic acid extractants for the preferential extraction of cobalt from nickel. The extractants evaluated were Cyanex 272, Cyanex 302 and Ionquest 801, each diluted in Isopar M at 0.5 M concentration (16% v/v). The test program generated extraction and stripping isotherms and generated strip liquor and raffinate samples for the production of cobalt and nickel precipitates.

4.1 Evaluation of Extractants

Three pH extraction isotherms for cobalt and nickel were generated for Cyanex 272, Cyanex 302 and Ionquest 801. A sample of SX Feed (purified raffinate) was contacted with the extractants at 0.5 M in Isopar M at various equilibrium pH. The distribution of cobalt and nickel in the organic and aqueous phases were determined as a function of pH. The tests were conducted to determine which extractant and at what pH would achieve the maximum extraction of cobalt from nickel. Test details are provided in Appendix C and the results are shown graphically in Figures 9 to 11.

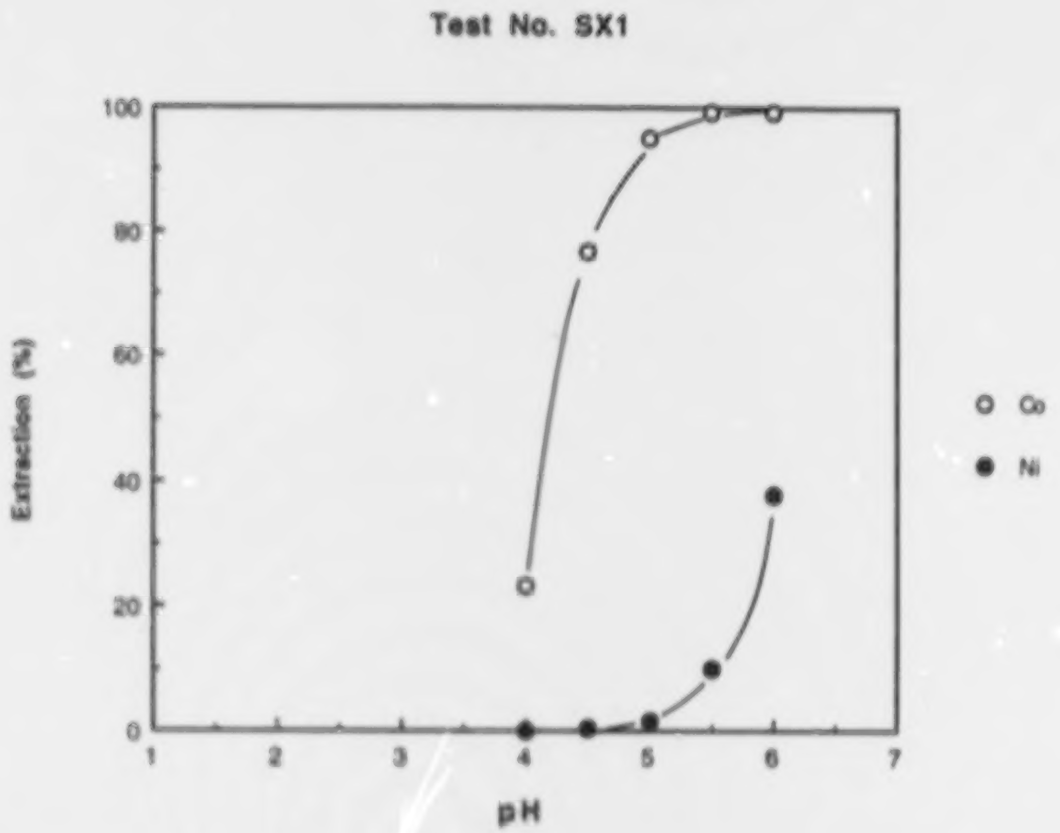


Figure 9: The extraction of Co and Ni from purified raffinate solution by 0.5 M Cyanex 272 in Isopar M.

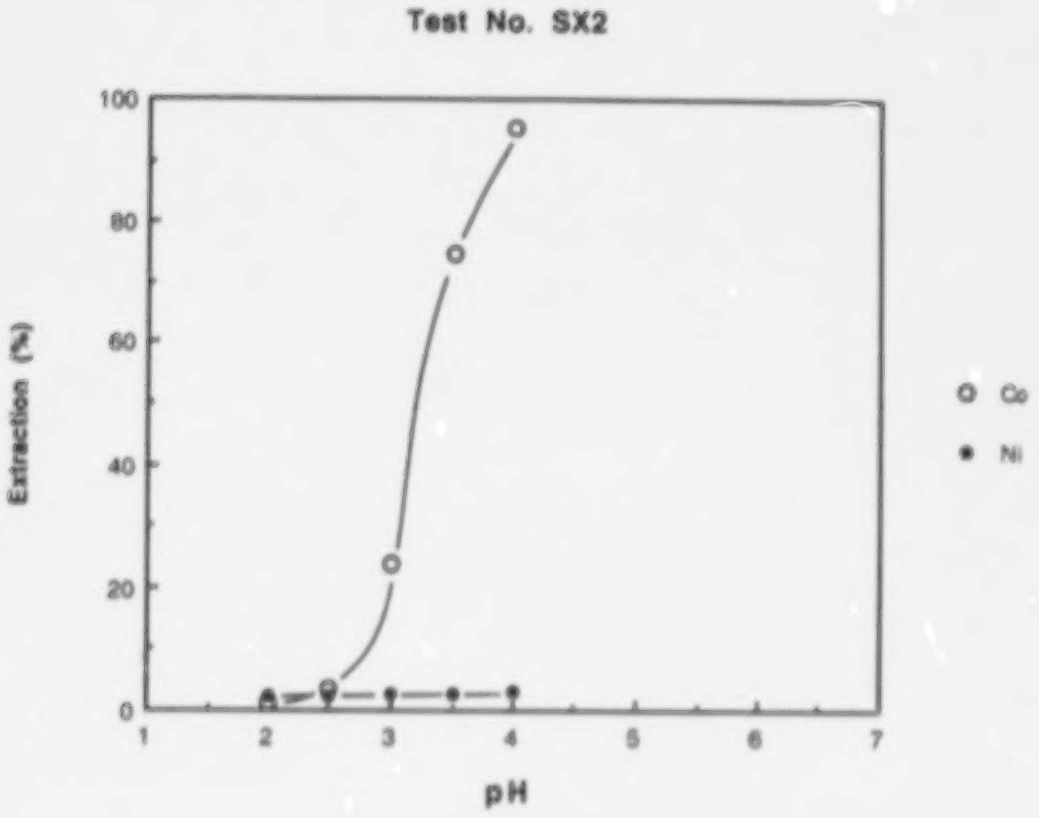


Figure 10: The extraction of Co and Ni from purified raffinate solution by 0.5 M Cyanex 302 in Isopar M.

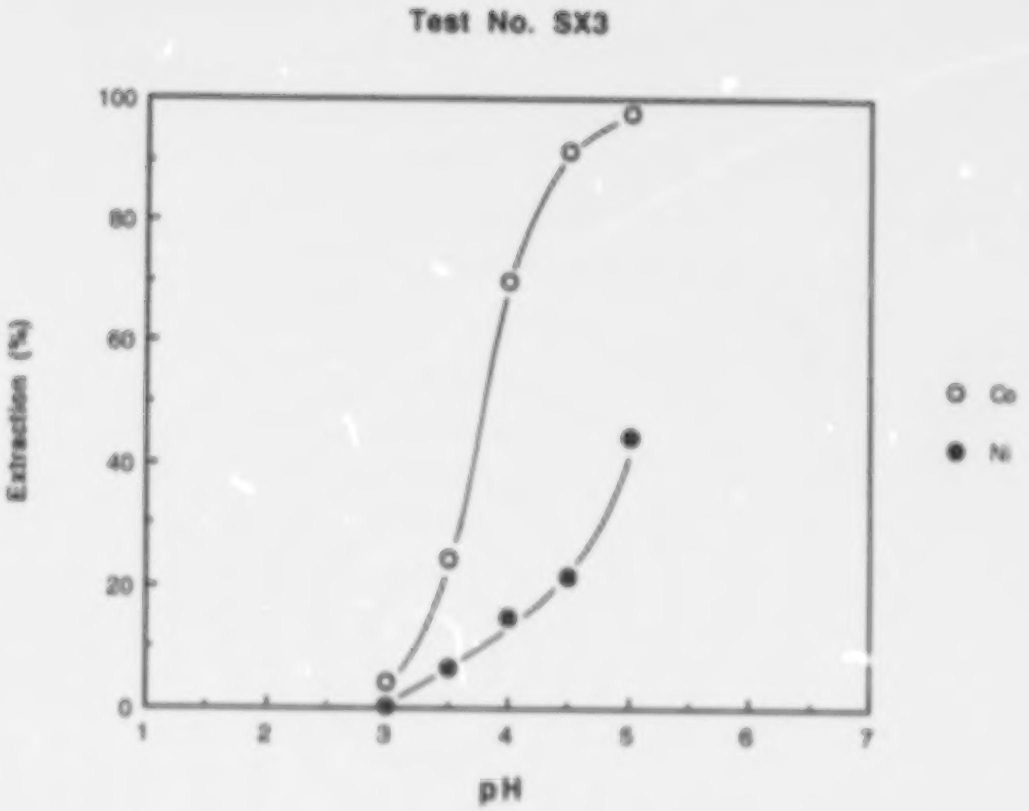


Figure 11: The extraction of Co and Ni from purified raffinate solution by 0.5 M Ionquest 801 in Isopar M.

The figures clearly show the separation of cobalt from nickel. As shown in Figure 9, Cyanex 272 performed the best in the pH range from 4 to 5. At pH 4.5, the extraction efficiency for cobalt was 77% with 0% extraction of nickel.

Figure 10 shows that Cyanex 302 extractant also performed very well with very good separation of cobalt from nickel in the pH 3.5 to 4.0 range. Cyanex 302 extracted cobalt at a lower pH than Cyanex 272 and therefore would require a stronger acid concentration for stripping.

Ionquest 801 did not perform as well as the Cyanex reagents. The graph in Figure 11 shows the co-extraction of nickel with cobalt.

The pH isotherm tests showed that Cyanex 272 performed better than the other extractants and therefore further testing was conducted only with Cyanex 272 at an extraction equilibrium pH of 4.5.

4.2 Extraction Distribution Isotherm

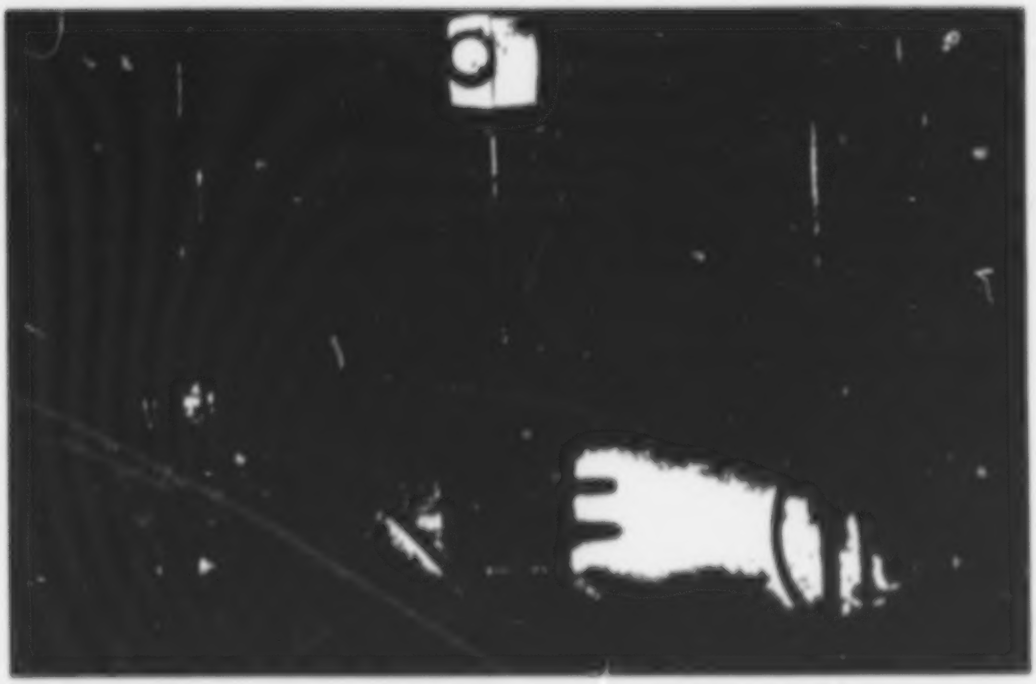
The extraction isotherm was prepared for the purified raffinate solution and Cyanex 272 by contacting the aqueous solution with the organic solution at various O/A ratios until extraction equilibrium was obtained at pH 4.5. The time required to reach equilibrium was approximately one minute as indicated by the colour change. The organic changed from colourless to a deep blue colour during the extraction as can be seen in Figure 12. The two phases from each contact were separated and the concentration of cobalt were determined in both phases. The results are shown graphically in Figure 13 and test details are provided in Appendix C.

The extraction isotherm shows that five stages would be required to extract cobalt from an SX feed containing 379 mg/L at an operating O/A ratio of 1/2. This would produce a loaded organic at 750 mg/L Co and a raffinate containing ~ 20 mg/L Co.

4.3 Preparation of Loaded Organic

A sample of loaded organic was prepared for stripping tests by three repeat contacts of 0.5 M Cyanex 272 organic with fresh portions of purified raffinate solution at an O/A of 1/10. An organic sample was prepared containing 940 mg/L Co and 8.4 mg/L Ni. Test details are provided in Appendix C, Test No. SX 5.

Summary



Before During After

Figure 12: A photograph showing the colour change of Cyanex 272 during the extraction of cobalt from purified uranium raffinate.

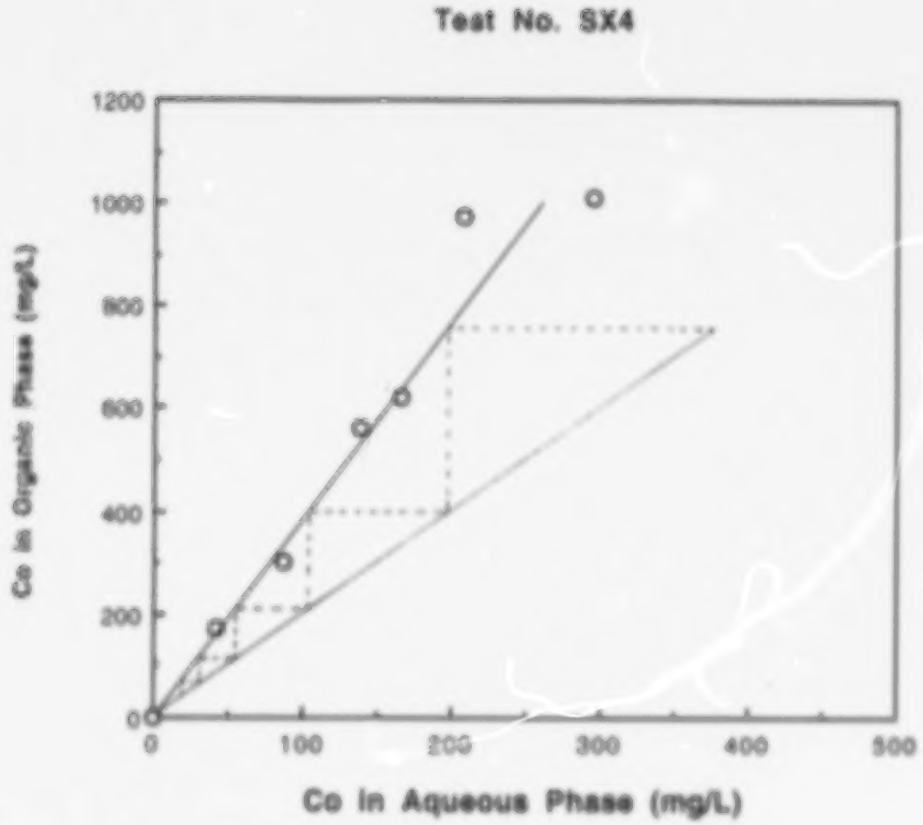


Figure 13: The equilibrium extraction of cobalt at pH 4.5 by 0.5 M Cyanex 272 and SX feed containing 379 mg/L Co showing the number of stages at an operating O/A ratio of 1/2.

4.4 Stripping Distribution Isotherm

The stripping isotherm was prepared for the loaded organic and 50 g/L H_2SO_4 strip solution by contacting the phases at various O/A ratios until stripping equilibrium was established.

The time required to reach equilibrium was easily determined by observation of the colour change. The cobalt loaded organic was a deep blue colour and during stripping the strip liquor turned pink and the stripped organic turned colourless. It took 6 minutes to reach equilibrium during stripping.

The results are plotted in Figure 14 and test details are provided in Appendix C, Test No. 6.

The stripping isotherm shows that only one stage would be required to produce a strip liquor containing 15,000 mg/L Co and a stripped organic with ~ 10 mg/L Co at an operating O/A ratio of 20/1.

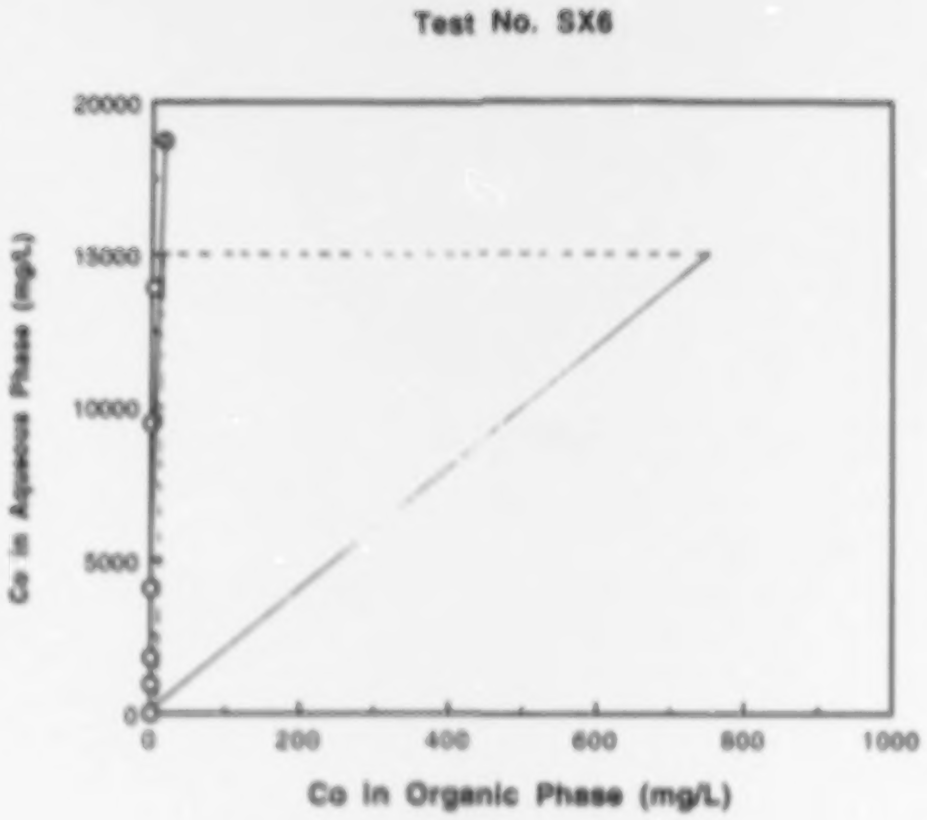


Figure 14: The equilibrium extraction of cobalt by 50 g/L H_2SO_4 from loaded organic containing 750 mg/L Co showing the number of stages at an operating O/A ratio of 20/1.

4.5 Preparation of Raffinate and Strip Liquor

Cobalt raffinate and strip liquor samples were prepared for subsequent nickel and cobalt precipitation tests.

The raffinate was prepared by contacting the Co, Ni feed solution with fresh 0.5 M Cyanex 272 organic continuously in a single stage laboratory scale mixer-settler unit as shown in Figure 15. The extraction was carried out at pH 4.5 at an O/A flow ratio of 1/6.

The loaded organic produced during the preparation of raffinate was combined with other loaded organic samples, prepared at pH 4.5, from previous solvent extraction tests. The composite of all loaded organics was used as feed for the production of a strip liquor sample.

The strip liquor was produced by contacting the loaded organic composite with 50 g/L H_2SO_4 at an O/A ratio of 30/1. During the stripping contact the colour changed from dark blue to pink over a six minute period, visually confirming the stripping kinetics. Shortly after the contact, precipitation of calcium sulphate occurred in the strip liquor. Cyanex 272 co-extracted calcium at pH 4.5. The loaded organic was analysed and found to contain 91 mg/L Ca. Since the stripping was done at an O/A ratio of 30/1, calcium was concentrated 30 times to 2700 mg/L Ca. This was well above the solubility for calcium sulphate. After completion of the precipitation, the strip liquor contained 596 mg/L soluble Ca. The strip liquor also contained 1120 mg/L Mg. Analyses on the raffinate, strip liquor and loaded organic are shown in Table 11, and test details are provided in Appendix C, Test No. SX 7.

Figure 15: A photograph showing the laboratory scale mixer-settler unit used for the preparation of raffinate and loaded organic.

Summary

Table 11: Analyses of Cobalt Raffinate, Strip Liquor and Loaded Organic

Element	Analyses (mg/L) Co Raffinate	Strip Liquor	Loaded Organic
Al	< 0.10	21	11
As	4.8	<10	0.7
Ca	488	596	91
Co	128	13750	550
Fe	<0.02	1.36	1.6
Mg	512	1120	45
Ni	3960	639	17
Zn	0.02	185	27
pH	4.5	1.7	-

The analyses in Table 11 show that complete separation of cobalt from nickel was not obtained. Because only one stage of extraction had been employed, 128 mg/L Co remained unextracted in the raffinate with 3960 mg/L Ni. The co-extracted nickel was stripped with the cobalt producing a strip liquor containing 13750 mg/L Co and 639 mg/L Ni.

Improved cobalt-nickel separation would be expected in a continuous counter-current extraction process, and if further separation efficiencies would be required, then the loaded organic could be scrubbed with a high concentration cobalt solution, such as a small bleed of the strip liquor.

Improved separation of cobalt from calcium and magnesium could be accomplished by carrying out the extraction at a lower equilibrium pH. An extraction pH of 4.0 may be sufficient. Alternately, cobalt and nickel could be precipitated from the purified raffinate solution prior to solvent extraction. The precipitate could be re-dissolved in a smaller volume of dilute acid producing a more concentrated and purer solution for the SX feed.

6. Precipitation of Ni from Cobalt Raffinate and Co from Strip Liquor

Two precipitation tests were conducted to produce a nickel carbonate and a cobalt carbonate for product evaluation.

Test No. 24 was the precipitation of nickel from the cobalt raffinate and Test No. 25 was the precipitation of cobalt from the strip liquor. In both tests, the precipitation was carried out at 50°C over a 30 minute period. A 200 g/L Na_2CO_3 solution was slowly added to the feed solution to adjust the pH to 8.67. The results are summarized in Table 12 and test details are provided in Appendix B.

Table 12: Nickel and Cobalt Product Analyses

Element	Analyses (%)	
	Nickel Carbonate (Test No. 24)	Cobalt Carbonate (Test No. 25)
Al	< 0.10	0.30
As	0.046	0.02
Ca	4.43	1.42
Co	1.51	40.2
Fe	<0.05	0.06
Mg	2.26	1.78
Ni	39.4	1.90
U	0.00005	0.00013
Zn	0.004	0.52
Ra_{226} (Bq/g)	0.02	0.08

The analyses in Table 12 demonstrate that nickel and cobalt products can be produced with very low levels of aluminum, arsenic, iron, zinc, uranium and radium. However, some calcium and magnesium were carried over into the products, and some cross-contamination of Ni and Co occurred, which would not be expected in a multi-stage countercurrent process.

CONCLUSIONS

1. It was determined that the addition of hydrogen peroxide to the uranium raffinate was required to oxidize residual ferrous to ferric and complete the precipitation of iron and arsenic.

2. It was determined that, during first stage precipitation, the raffinate must be neutralized with lime to between 4.5 to 5.0 and the addition of ferric sulphate must be at least ≥1/1 Fe^{+3}/As molar ratio.

3. The recovery of co-precipitated cobalt and nickel from the first stage precipitate was possible by repulping the precipitate in pH 3.0 to 3.5 sulphuric acid.

4. The removal of radium by treatment with 25 mg/L barium chloride was very effective.

5. Precipitation of residual arsenic during the second stage of precipitation required ferric sulphate addition at ≥ 4/1 Fe^{+3}/As molar ratio.

6. Bulk precipitation of cobalt/nickel from purified raffinate solution with NaHS was not very efficient, recovering less than 50% of the values when using a stoichiometric amount of sulphide. An excess amount of sulphide would be necessary, which would require further treatment to remove it from the barren solution prior to discharge.

7. Bulk precipitation of cobalt/nickel from purified raffinate solution with $Ca(OH)_2$ precipitant was very efficient. However, the weight of the dried hydroxide precipitate was 50% heavier than the carbonate precipitates.

8. Bulk precipitation of cobalt/nickel from purified raffinate solution with Na_2CO_3 precipitant was very efficient. However, the precipitation had to be conducted at 50°C to produce a precipitate more amenable to filtration.

9. The solvent extraction tests showed that Cyanex 272 extractant performed better than Cyanex 302 or Ionquest 801, for the selective removal of cobalt from the Co/Ni solution.

10. The rate of extraction by Cyanex 272 was fast, as observed by the colour change. The kinetics for extraction was approximately one minute. The extraction isotherm showed that five stages of extraction will be required. Phase disengagement during extraction with Cyanex 272 was extremely fast.

11. Stripping of the loaded organic required 6 minute contact with 50 g/L sulphuric acid. The stripping isotherm showed that only one stage will be required.

12. The products produced demonstrated that cobalt and nickel can be successfully recovered with a minimum amount of impurities.

APPENDIX A: Test Details: Raffinate Pretreatment

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: January 1st, 1992

Test No. 1

Objective: To determine the conditions for the removal of impurities by precipitation with minimum losses of cobalt and nickel. To study the effect of pH without barium chloride or ferric sulphate.

Procedure:
1 Transfer 7 L of raffinate to a 10 L reaction vessel. Include agitator, impeller, baffle and air purging.
2 Do not add barrium chloride or ferric sulphate.
3 Slowly neutralize the solution with 20 % w/w Ca(OH)2 slurry.
4 Take thief samples at pH 3, 4, 5 and 6.
5 Filter the samples through 0.6 µm paper and submit the filtrates for Al, As, Co, Fe, Ni and Ra226.
6 Record the wet and dry weights of the filter cakes.

Feed: Uranium raffinate

Conditions:

BaCl2 • 2 H2O	0	mg/L
Fe+3/As	0	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	Various	

Data:

Product			Amount	Analyses (mg/L, Bq/L)						Precipitated (%)					
				Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Feed	pH	1	7000 mL	2100	5300	538	69.0	5400	55	0.0	0.0	0.0	0.0	0.0	0.0
Solution	pH	3	7336 mL	1760	4280	486	31.9	4980	25	12.2	15.4	5.3	51.5	3.4	52.4
Solution	pH	4	7475 mL	56.5	630	423	1.0	4340	2.5	97.1	87.3	16.0	98.5	14.2	95.1
Solution	pH	5	7491 mL	2.9	580	402	0.2	4190	1.0	99.9	88.3	20.0	99.7	17.0	98.1
Solution	pH	6	7504 mL	0.1	457	374	0.04	4040	0.25	100.0	90.8	25.5	99.9	19.8	99.5

Reagent Addition: **Slurry Sampled:**

pH	20% w/w Ca(OH)2 mL	1 g/L BaCl2 mL	100 g/L Fe2(SO4)3 mL	Wet wt. g	Dry wt. g	Filtrate volume mL	emf mV
1	0	0	0				479
3	420			176.9	38.1	1680	341
4	106			318.5	80.4	1580	265
5	12			322.3	86.7	1540	346
6	10			398.2	97.4	1620	360

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	January 16, 1992

Test No. 2

Objective: To determine the conditions for the removal of impurities by precipitation with minimum losses of cobalt and nickel. To study the effect of pH with 25 mg/L barium chloride.

Procedure:

1 Transfer 7 L of raffinate to a 10 L reaction vessel. Include agitator, impeller, baffle and air purging.
2 Add 25 mg/L barium chloride.
3 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry.
4 Take thief samples at pH 3, 4, 5 and 6.
5 Filter the samples through 0.6 µm paper and submit the filtrates for Al, As, Co, Fe, Ni and Ra226.
6 Record the wet and dry weights of the filter cakes.

Feed: Uranium raffinate

Conditions:

$BaCl_2 \cdot 2H_2O$	25	mg/L
Fe+3/As	0	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	Various	

Data:

Product	Amount	Analyses (mg/L, Bq/L)						Precipitated (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Feed pH 1	7000 mL	2100	5300	536	69.0	5400	55	0.0	0.0	0.0	0.0	0.0	0.0
Solution pH 3	7503 mL	1750	4250	495	31.5	4900	2.5	10.7	14.0	1.4	51.1	2.7	95.1
Solution pH 4	7645 mL	102.0	750	452	0.9	4890	0.5	94.7	84.5	8.2	98.6	1.1	99.0
Solution pH 5	7664 mL	3.1	570	422	0.2	4510	0.14	99.8	88.2	14.1	99.6	8.6	99.7
Solution pH 6	7677 mL	0.1	466	380	0.04	4020	0.05	100.0	90.4	22.5	99.9	18.4	99.9

Reagent Addition:

pH	20% w/w $Ca(OH)_2$ mL	1 g/L $BaCl_2$ mL	100 g/L $Fe_2(SO_4)_3$ mL
1	0	175	0
3	410		
4	107		
5	15		
6	10		

Slurry Sampled:

Wet wt. g	Dry wt. g	Filtrate volume mL	emf mV
			478
191.2	35.2	1680	321
372.3	69.0	1490	311
325.6	79.5	1535	311
381.6	100.0	1780	355

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	January 16, 1992

Test No. 3

Objective: To determine the conditions for the removal of impurities by precipitation with minimum losses of cobalt and nickel. To study the effect of pH with 0.5/1 Fe+3/As.

Procedure:
1 Transfer 7 L of raffinate to a 10 L reaction vessel. Include agitator, impeller, baffle and air purging.
2 Add 691 mL of 100 g/L Fe2(SO4)3H9H2O (20 g/L Fe+3).
3 Slowly neutralize the solution with 20 % w/w Ca(OH)2 slurry.
4 Take three samples at pH 3, 4, 5 and 6.
5 Filter the samples through 0.8 µm paper and submit the filtrates for Al, As, Co, Fe, Ni and Ra226.
6 Record the wet and dry weights of the filter cakes.

Feed: Uranium raffinate

Conditions:

BaCl2 • 2 H2O	0	mg/L
Fe+3/As	0.5/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	Various	

Data:

Product			Amount	Analyses (mg/L, Bq/L)						Precipitated (%)					
				Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Feed	pH	1	7000 mL	2100	5300	538	2043	5400	55	0.0	0.0	0.0	0.0	0.0	0.0
Solution	pH	3	8075 mL	1530	1050	435	47.8	4560	4.5	16.0	77.1	6.7	97.3	2.6	90.6
Solution	pH	4	8200 mL	818	630	418	44.6	4520	3.0	54.4	86.1	9.0	97.4	1.9	93.6
Solution	pH	5	8284 mL	6.5	330	390	24.6	4150	1.2	99.6	92.6	14.2	98.6	9.1	97.4
Solution	pH	6	8307 mL	1.2	158	310	2.74	3240	0.25	99.9	96.5	31.6	99.8	28.8	99.5

Reagent Addition: **Slurry Sampled:**

pH	20% w/w Ca(OH)2 mL	1 g/L BaCl2 mL	100 g/L Fe2(SO4)3 mL	Wet wt. g	Dry wt. g	Filtrate volume mL	emf mV
1	0	0	691				479
3	480			252.1	60.6	1900	284
4	90			257.8	67.3	1585	279
5	67			348.5	107.2	1695	247
6	18			466.6	141.2	2010	265

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	January 16, 1992

Test No. 4

Objective: To determine the conditions for the removal of impurities by precipitation with minimum losses of cobalt and nickel. To study the effect of pH with 1/1 Fe+3/As.

Procedure:
1 Transfer 7 L of raffinate to a 10 L reaction vessel. Include agitator, impeller, baffle and air purging.
2 Add 1382 mL of 100 g/L Fe2(SO4)3•9H2O (20 g/L Fe+3).
3 Slowly neutralize the solution with 20 % w/w Ca(OH)2 slurry.
4 Take thief samples at pH 3, 4, 5 and 6.
5 Filter the samples through 0.6 µm paper and submit the filtrates for Al, As, Co, Fe, Ni and Ra226.
6 Record the wet and dry weights of the filter cakes.

Feed: Uranium raffinate

Conditions:

BaCl2 • 2 H2O	0	mg/L
Fe+3/As	1/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	Various	

Data:

Product			Amount	Analyses (mg/L, Bq/L)						Precipitated (%)					
				Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Feed	pH	1	7000 mL	2100	5300	538	4018	5400	55	0.0	0.0	0.0	0.0	0.0	0.0
Solution	pH	3	8830 mL	1600	415	402	120	4170	10	3.9	90.1	5.7	96.2	2.6	77.1
Solution	pH	4	8996 mL	1220	340	380	92.2	4020	5.0	25.3	91.8	9.2	97.1	4.3	88.3
Solution	pH	5	9134 mL	5.7	118	330	47.2	3640	1.6	99.6	97.1	20.0	98.5	12.0	95.7
Solution	pH	6	9162 mL	0.1	40	254	2.40	2870	0.45	100.0	99.0	38.2	99.9	30.4	98.9

Reagent Addition: **Slurry Sampled:**

pH	20% w/w Ca(OH)2 mL	1 g/L BaCl2 mL	100 g/L Fe2(SO4)3 mL	Wet wt. g	Dry wt. g	Filtrate volume mL	emf mV
1	0	0	1382				479
3	580			307.2	79.4	1780	372
4	120			347.1	94.1	1735	299
5	110			451.0	121.3	1680	240
6	22			721.8	180.8	2300	235

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	January 16, 1992

Test No. 4a

Objective: To conduct a 1st stage precipitation test to generate a precipitate for Co-Ni recovery tests and feed solution for 2nd stage precipitation tests.

Procedure:
1 Transfer 28 L of raffinate to a 50 L reaction vessel. Include agitator, impeller, baffle and air purging.
2 Add 700 mL of 1 g/L $BaCl_2 \cdot 2H_2O$ solution.
3 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 5.
4 Stir slurry for 30 minutes.
5 Filter the samples through 0.6 µm paper and submit the filtrates for Al, As, Co, Fe, Ni and Ra226.
6 Record the wet weight of the filter cake and submit sample for moisture and analyses.

Feed: Uranium raffinate

Conditions:

$BaCl_2 \cdot 2H_2O$	25	mg/L
Fe^{+3}/As	0	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	5.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	30680 mL	0.77	520	389	0.10	4070	0.12	0.0	10.2	86.9	0.2	90.7	0.0
Residue	1283 g	4.7	11.0	0.14	0.14	1.0	0.70	100.0	89.8	13.1	99.8	9.3	100.0
Head (calc.)	28000 mL	2145	5609	490	64	4918		100.0	100.0	100.0	100.0	100.0	100.0
Head (assay)		2100	5300	538	69	5400	55						

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: January 24, 1992

Test No. 6

Objective: To determine the conditions for the selective recovery of Co and Ni from 1st stage precipitate.
Repulp precipitate in H2SO4 at pH 2.0

Procedure:
1 Transfer 812.7 g of wet precipitate to a 2 L beaker.
2 Add 1 L of diluted sulphuric acid and adjust solution to pH 2.
3 Stir slurry at 20 °C for 30 minutes.
4 Filter the slurry through 0.6 µm paper and wash the residue with 1.5 displacement wash solution.
5 Submit the filtrate and residue for Al, As, Co, Fe, Ni and Ra226.
6 Record the wet and dry weights of the filter cake.

Feed: 812.7 g 1st stage precipitate   Moisture content: 71 %

Conditions:

Temperature	20	°C
Reaction Time	0.5	h
pH	2.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1620 mL	5780	12200	187	203	1390	18	96.0	96.1	95.9	83.4	95.9	2.2
Residue	146.6 g	0.30	0.62	0.01	0.05	0.07	1.0	4.0	3.9	4.1	16.6	4.1	97.8
Head (calc.)	235.4 g	4.65	9.82	0.15	0.19	1.12	0.64	100	100	100	100	100	100
Head (assay)		4.68	10.20	0.14	0.24	1.00	0.70						

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: January 24, 1992

Test No. 6

Objective: To determine the conditions for the selective recovery of Co and Ni from 1st stage precipitate.
Repulp precipitate in H2SO4 at pH 2.5

Procedure:
1 Transfer 818.4 g of wet precipitate to a 2 L beaker.
2 Add 1 L of diluted sulphuric acid and adjust solution to pH 2.5.
3 Stir slurry at 20 °C for 30 minutes.
4 Filter the slurry through 0.6 µm paper and wash the residue with 1.5 displacement wash solution.
5 Submit the filtrate and residue for Al, As, Co, Fe, Ni and Ra226.
6 Record the wet and dry weights of the filter cake.

Feed: 818.4 g 1st stage precipitate. Moisture content 71 %

Conditions:

Temperature	20	°C
Reaction Time	0.5	h
pH	2.5	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1670 mL	6430	13600	207	224	1550	19	97.0	95.3	97.6	83.9	97.3	2.5
Residue	143.9 g	0.23	0.77	0.01	0.05	0.05	0.85	3.0	4.7	2.4	16.1	2.7	97.5
Head (calc.)	237.1 g	4.67	10.05	0.15	0.19	1.12	0.53	100	100	100	100	100	100
Head (assay)		4.68	10.20	0.14	0.24	1.00	0.70						

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reichus
Date: January 24, 1992

Test No. 7

Objective: To determine the conditions for the selective recovery of Co and Ni from 1st stage precipitate
Repulp precipitate in H2SO4 at pH 3.0

Procedure:
1 Transfer 819.7 g of wet precipitate to a 2 L beaker
2 Add 1 L of diluted sulphuric acid and adjust solution to pH 3.0
3 Stir slurry at 20 °C for 30 minutes
4 Filter the slurry through 0.6 µm paper and wash the residue with 1.5 displacement wash solution
5 Submit the filtrate and residue for Al, As, Co, Fe, Ni and Ra226
6 Record the wet and dry weights of the filter cake

Feed: 819.7 g 1st stage precipitate Moisture content 71 %

Conditions:

Temperature	20	°C
Reaction Time	0.5	h
pH	3.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1330 mL	1010	1740	196	2	1432	0.95	12.0	10.0	81.8	2.5	71.8	0.1
Residue	252.7 g	3.88	8.23	0.02	0.06	0.30	0.55	88.0	90.0	18.2	97.5	28.2	99.9
Head (calc.)	237.5 g	4.69	8.73	0.13	0.06	1.13	0.59	100	100	100	100	100	100
Head (assay)		4.66	10.20	0.14	0.24	1.06	0.70						

Project No. LR 4234
Client: Midwest Joint Ventures
Project Technician: Warren Reishus
Date: January 24, 1992

Test No. 8

Objective: To determine the conditions for the selective recovery of Co and Ni from 1st stage precipitate.
Repulp precipitate in H2SO4 at pH 3.5

Procedure:
1 Transfer 822.1 g of wet precipitate to a 2 L beaker
2 Add 1 L of diluted sulphuric acid and adjust solution to pH 3.5
3 Stir slurry at 20 °C for 30 minutes
4 Filter the slurry through 0.6 µm paper and wash the residue with 1.5 displacement wash solution
5 Submit the filtrate and residue for Al, As, Co, Fe, Ni and Ra226
6 Record the wet and dry weights of the filter cake

Feed: 822.1 g 1st stage precipitate Moisture content 71 %

Conditions:
Temperature 20 °C
Reaction Time 0.5 h
pH 3.5

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1290 mL	170	479	154	0.29	1140	0.50	2.0	2.4	70.3	0.1	59.2	0.0
Residue	245.9 g	4.41	10.00	0.03	0.20	0.41	0.65	98.0	97.6	29.7	99.9	40.8	100.0
Head (calc.)	238.2 g	4.66	10.63	0.12	0.21	1.04	0.67	100	100	100	100	100	100
Head (assay)		4.68	10.20	0.14	0.24	1.00	0.70						

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reshua
Date: January 27, 1992

Test No. 9

Objective: To conduct a 2nd stage precipitation test for the removal of radium.
To study the effect with 2 mg/L barium chloride.

Procedure:
1. Transfer 1.8 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2. Add 3.6 mL of 1 g/L $BaCl_2 \cdot 2H_2O$ during vigorous stirring.
3. Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 4.
4. Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5. Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

$BaCl_2 \cdot 2H_2O$	2	mg/L
Fe+3/As	0	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1804 mL	0.77	485	370	0.10	3870	0.12	100.0	95.4	95.3	100.0	95.3	100.0
Residue								0.0	4.6	4.7	0.0	4.7	0.0
Head (calc.)								100.0	100.0	100.0	100.0	100.0	100.0
Head (assay)	1800 mL	0.77	520	389	0.10	4070	0.12						

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	January 27, 1992

Test No. 10

Objective: To conduct a 2nd stage precipitation test for the removal of radium.
To study the effect with 10 mg/L barium chloride.

Procedure:
1 Transfer 1.8 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2 Add 18 mL of 1 g/L $BaCl_2 \cdot 2H_2O$ during vigorous stirring.
3 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 4.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5 Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

$BaCl_2 \cdot 2H_2O$	10	mg/L
Fe+3/As	0	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1818 mL	0.76	502	376	0.10	3930	0.03	100.0	97.5	97.6	100.0	97.5	25.3
Residue								0.0	2.5	2.4	0.0	2.5	74.8
Head (calc.)								100.0	100.0	100.0	100.0	100.0	100.0
Head (assay)	1800 mL	0.77	520	389	0.10	4070	0.12						

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	January 27, 1992

Test No. 11

Objective: To conduct a 2nd stage precipitation test for the removal of radium.
To study the effect with 25 mg/L barium chloride.

Procedure:

1 Transfer 1.8 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2 Add 45 mL of 1 g/L $BaCl_2 \cdot 2H_2O$ during vigorous stirring.
3 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 4.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5 Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

$BaCl_2 \cdot 2H_2O$	25	mg/L
Fe^{+3}/As	0	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1845 mL	0.76	489	368	0.10	3820	0.03	100.0	96.4	97.0	100.0	96.2	25.6
Residue								0.0	3.6	3.0	0.0	3.8	74.4
Head (calc.)								100.0	100.0	100.0	100.0	100.0	100.0
Head (assay)	1800 mL	0.77	520	389	0.10	4070	0.12						

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	January 27, 1992

Test No. 12

Objective: To conduct a 2nd stage precipitation test for the removal of radium.
To study the effect with 50 mg/L barium chloride.

Procedure:

1. Transfer 1.8 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2. Add 90 mL of 1 g/L $BaCl_2 \cdot 2H_2O$ during vigorous stirring.
3. Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 4.
4. Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5. Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

$BaCl_2 \cdot 2H_2O$	50	mg/L
Fe^{+3}/As	0	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1890 mL	0.74	486	368	0.10	3820	0.03	100.0	98.1	99.3	100.0	98.6	26.3
Residue								0.0	1.9	0.7	0.0	1.4	73.8
Head (calc.)								100.0	100.0	100.0	100.0	100.0	100.0
Head (assay)	1800 mL	0.77	520	389	0.10	4070	0.12						

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: January 30, 1992

Test No. 13

Objective: To conduct a 2nd stage precipitation test for the removal of Arsenic.
To study the effect with 0.25/1 Fe^{+3}/As molar ratio.

Procedure:
1 Transfer 1.6 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2 Add 7.7 mL of 100 g/L $Fe_2(SO_4)_3 \cdot 9H$[illegible]uring vigorous stirring.
3 Slowly neutralize the solution with 20[illegible] $Ca(OH)_2$ slurry to pH 4.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5 Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

$BaCl_2 \cdot 2H_2O$	0	mg/L
Fe^{+3}/As	0.25/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1570 mL	1.29	434	400	14.4	4150			81.9	100.0	14.7	100.0	
Residue									18.1	0.0	85.3	0.0	
Head (calc.)									100.0	100.0	100.0	100.0	
Head (assay)	1600 mL	0.77	520	389	96	4070							

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: January 30, 1992

Test No. 14

Objective: To conduct a 2nd stage precipitation test for the removal of Arsenic.
To study the effect with 0.5/1 Fe^{+3}/As molar ratio.

Procedure:
1 Transfer 1.6 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2 Add 15.5 mL of 100 g/L $Fe_2(SO_4)_3 \cdot 9H_2O$ during vigorous stirring.
3 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 4.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5 Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

$BaCl_2 \cdot 2H_2O$	0	mg/L
Fe^{+3}/As	0.5/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1625 mL	1.49	334	386	33.8	4000			65.2	100.0	17.7	100.0	
Residue									34.8	0.0	82.3	0.0	
Head (calc.)									100.0	100.0	100.0	100.0	
Head (assay)	1600 mL	0.77	520	389	194	4070							

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: January 30, 1992

Test No. 15

Objective: To conduct a 2nd stage precipitation test for the removal of Arsenic.
To study the effect with 1/1 Fe+3/As molar ratio.

Procedure:
1 Transfer 1.6 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2 Add 31 mL of 100 g/L Fe2(SO4)3•9H2O during vigorous stirring.
3 Slowly neutralize the solution with 20 % w/w Ca(OH)2 slurry to pH 4.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5 Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

BaCl2 • 2 H2O	0	mg/L
Fe+3/As	1/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1655 mL	1.75	243	379	57.7	3940			48.3	100.0	15.4	100.0	
Residue									51.7	0.0	84.6	0.0	
Head (calc.)									100.0	100.0	100.0	100.0	
Head (assay)	1600 mL	0.77	520	389	388	4070							

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: January 30, 1992

Test No. 16

Objective: To conduct a 2nd stage precipitation test for the removal of Arsenic.
To study the effect with 5/1 Fe+3/As molar ratio.

Procedure:
1 Transfer 1.6 L of 1st stage solution at pH 4 to a 2 L reaction vessel.
2 Add 155 mL of 100 g/L $Fe_2(SO_4)_3 \cdot 9H_2O$ during vigorous stirring.
3 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 4.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.
5 Record the wet and dry weights of the filter cake.

Feed: 1st stage solution at pH 4.0 (Generatated in Test No 4a.)

Conditions:

$BaCl_2 \cdot 2H_2O$	0	mg/L
Fe+3/As	5/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Solution	1735 mL	3.50	17	359	241	3750			3.5	100.0	13.5	100.0	
Residue									96.5	0.0	86.5	0.0	
Head (calc.)									100.0	100.0	100.0	100.0	
Head (assay)	1600 mL	0.77	520	389	1938	4070							

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 4, 1992

Test No. 17

Objective: To conduct a 1st stage precipitation test at pH 5 on oxidized raffinate feed.
To recover Co & Ni from precipitate by repulping in pH 3.5 H2SO4 solution.

Procedure:
1 Transfer 1.0 L of 1st stage solution to a 2 L reaction vessel.
2 Add H_2O_2 slowly until no further change in emf. This will be ~625 mV.
3 Add 25 mL of 1 g/L $BaCl_2 \cdot 2H_2O$ during vigorous stirring.
4 Add 200 mL of 100 g/L $Fe_2(SO_4)_3 \cdot 9H_2O$.
5 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 5.
6 Filter the sample through 0.6 µm paper and repulp in pH 3.5 H_2SO_4.
7 Add pH 1 H_2SO_4 to slurry to maintain pH 3.5 for 30 min.

Feed: Uranium Raffinate 603 mV (added 2 mL of 30 % w/w H_2O_2 per 1 L of raffinate)

Conditions:

$BaCl_2 \cdot 2H_2O$	25	mg/L
Fe^{+3}/As	1/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	5.0	

Data: 1st stage precitation.

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni		Al	As	Co	Fe	Ni	
1st stage sol'n	1408 mL	3.8	0.5	362	27.4	3800		0.3	0.0	94.7	0.9	99.1	
Precipitate								99.7	100.0	5.3	99.1	0.9	
Head (calc.)								100.0	100.0	100.0	100.0	100.0	
Head (assay)	1000 mL	2100	5300	538	4069	5400							

Data: Recovery of Co & Ni from precipitate. (Repulp sol'n pH 3.5).

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni		Al	As	Co	Fe	Ni	
Repulp Sol'n	1070 mL	1009	13.9	24	10.7	42		51.5	0.3	90.7	0.3	90.6	
Precipitate	59.3 g							48.5	99.7	9.3	99.7	9.4	
Head (calc.)								100.0	100.0	100.0	100.0	100.0	
Head (assay)													

Data: Overall recovery in solution.

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni		Al	As	Co	Fe	Ni	
Solution	2478 mL	438	6	216	20	2177		51.7	0.3	99.5	1.2	99.9	
Precipitate	59.3 g							48.3	99.7	0.5	98.8	0.1	
Head (calc.)								51.7	0.3	99.5	1.2	99.9	
Feed (assay)	1000 mL	2100	5300	538	4069	5400							

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	February 4, 1992

Test No. 18

Objective: To conduct a 1st stage precipitation test at pH 6 on oxidized raffinate feed.
To recover Co & Ni from precipitate by repulping in pH 3.5 H_2SO_4 solution.

Procedure:

1 Transfer 1.0 L of 1st stage solution to a 2 L reaction vessel.
2 Add H_2O_2 slowly until no further change in emf. This will be ~625 mV.
3 Add 25 mL of 1 g/L $BaCl_2 \cdot 2H_2O$ during vigorous stirring.
4 Add 200 mL of 100 g/L $Fe_2(SO_4)_3 \cdot 9H_2O$.
5 Slowly neutralize the solution with 20 % w/w $Ca(OH)_2$ slurry to pH 6.
6 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Ra226.

Feed: Uranium Raffinate 603 mV (added 2 mL of 30 % w/w H_2O_2 per 1 L of raffinate)

Conditions:

$BaCl_2 \cdot 2H_2O$	25	mg/L
Fe^{+3}/As	1/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	6.0	

Data: 1st stage precitation.

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
1st stage sol'n	1436 mL	0.1	0.1	215	0.5	2540	0.35	0.0	0.0	57.4	0.0	67.5	6.3
Precipitate	66.6 g							100.0	100.0	42.6	100.0	32.5	93.7
Head (calc.)								100.0	100.0	100.0	100.0	100.0	100.0
Head (assay)	1000 mL	2100	5300	538	4069	5400	8.00						

Data: Recovery of Co & Ni from precipitate. (Repulp sol'n pH 3.5).

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni		Al	As	Co	Fe	Ni	
Repulp Sol'n	1150 mL	676	9.1	179	5.1	1410		37.0	0.2	89.8	0.1	93	
Residue	66.6 g							63.0	99.8	10.2	99.9	7.5	
Head (calc.)								100.0	100.0	100.0	100.0	100.0	
Head (assay)													

Data: Overall recovery in solution.

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni		Al	As	Co	Fe	Ni	
Solution	2586 mL	301	4	199	3	2037		37.0	0.2	95.6	0.2	97.6	
Precipitate	66.6 g							63.0	99.8	4.4	99.8	2.4	
Head (calc.)								37.0	0.2	95.6	0.2	97.6	
Feed (assay)	1000 mL	2100	5300	538	4069	5400							

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 7, 1992
Test No. 19

Objective: To conduct a large scale raffinate pretreatment test to generate a purified raffinate solution.

Procedure:

1 Transfer 50 L of uranium raffinate to a 70 L reaction vessel.
2 Add H2O2 slowly until no further change in emf. This will be ~625 mV.
3 Add 125 mL of 10 g/L BaCl2 • 2H2O during vigorous stirring.
4 Add 10 L of 100 g/L Fe2(SO4)3 • 9H2O.
5 Slowly neutralize the solution with 25 % w/w Ca(OH)2 slurry to pH 5.
6 Filter the sample through 0.6 µm paper and wash precipate with water.
7 Acidify 1st stage solution to pH4.
8 Add 140 mL of 10 g/L BaCl2 • 2H2O during vigorous stirring.
9 Add 175 mL of 100 g/L Fe2(SO4)3 • 9H2O.
10 Slowly neutralize the solution with 25 % w/w Ca(OH)2 slurry to pH 4.
11 Filter the sample through 0.6 µm paper and wash precipate with water.

Feed: Uranium Raffinate

Conditions:

1st stage			2nd stage		
BaCl2 • 2 H2O	25	mg/L	BaCl2 • 2 H2O	25	mg/L
Fe+3/As	1/1	molar ratio	Fe+3/As	1/1	molar ratio
Temperature	20	°C	Temperature	20	°C
Reaction Time	0.5	h	Reaction Time	0.5	h
pH	5.0		pH	4.0	

Data: 1st stage precitation.

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
1st stage sol'n	55 L	4.7	85.0	380	0.1	3990		0.2	1.7	77.0	0.0	80.6	
Precipitate								99.8	98.3	23.0	100.0	19.4	
Head (calc.)								100.0	100.0	100.0	100.0	100.0	
Head (assay)	50 L	2100	5300	538	3324	5400							

Data: 2nd stage precitation.

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
2nd stage sol'n	54 L	5.6	37.0	390	1.0	4000	0.04	0.3	0.7	73.2	0.0	74.8	
Precipitate								99.7	99.3	26.8	100.0	25.2	
Head (calc.)								100.0	100.0	100.0	100.0	100.0	
Head (assay)	54 L	2100	5300	538	3682	5400							

Data: Overall recovery in final purified raffinate solution.

Product	Amount	Analyses (mg/L, %, Bq/L)						Distribution (%)					
		Al	As	Co	Fe	Ni	Ra	Al	As	Co	Fe	Ni	Ra
Purified Sol'n	54 L	5.6	37.0	390	1.0	4000		0.3	0.8	79.0	0.0	80.8	
Precipitate								99.7	99.2	21.0	100.0	19.2	
Head (calc.)								100.0	100.0	100.0	100.0	100.0	
Head (assay)	50 L	2100	5300	538	3324	5400							

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 18, 1992
Test No. 19a

Objective: To re-treated the 2nd stage purified solution to precipitate more arsenic.

Procedure:

1 Transfer 48 L of 2nd stage solution to a 70 L reaction vessel.
2 Add H2O2 slowly until no further change in emf. This will be ~625 mV.
3 Add 265 mL of 100 g/L Fe2(SO4)3 • 9H2O.
4 Slowly neutralize the solution with 25 % w/w Ca(OH)2 slurry to pH 4.
5 Filter the sample through 0.6 µm paper.

Feed: 2nd stage solution from Test No. 19.

Conditions: 3rd stage

BaCl2 • 2 H2O	0	mg/L
Fe+3/As	4/1	molar ratio
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data: 3rd stage precitation.

Product	Amount	Analyses (mg/L, %, Bq/L)					
		Al	As	Co	Fe	Ni	Ra
1st stage sol'n Precipitate	48 L	5.86	5.96	379	0.54	3900	
Head (calc.)							
Head (assay)	48 L	5.6	37	390	1	4000	0.04

APPENDIX B: Test Details: Precipitation Tests

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 17, 1992

Test No. 20

Objective: To conduct a Co-Ni precipitation test on the purified raffinate solution using NaHS.

Procedure:
1 Transfer 1500 mL of raffinate to a 2 L reaction vessel. Include agitator, impeller, and baffle.
2 Slowly add 12.6 g of 47.5 % w/w NaHS solution.
3 Let react at 20 °C for 30 min.
4 Filter the sample through 0.6 μm paper and submit the filtrate for Al, As, Co, Fe, Ni and Zn.
5 Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Purified raffinate solution (from Test No. 19)

Conditions:

NaHS addition	100%	Stoichiometric
Temperature	20	°C
Reaction Time	0.5	h
pH	4.0	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	1640 mL	6.6	13.6	184	1.1	1900	9.9	75.8	31.6	53.5	44.9	52.4	69.0
Precipitate	7.3 g	0.05	0.66	3.6	0.03	38.8	0.1	24.2	68.4	46.5	55.1	47.6	31.0
Feed (calc.)	1500 mL	9.6	47	376	2.7	3966	15.7	100	100	100	100	100	100
Feed (assay)		5.6	37	390	1.0	4000	9.4						

Product		Ca	Mg	U	Ra
		(%)	(%)	(μg/g)	(Bq/L)
Precipitate		0.04	0.04	3.3	0.05

Comments: Filtrate was clear.
Filtrate was green colour.
Good filtration.

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	February 17, 1992

Test No. 21

Objective: To conduct a Co-Ni precipitation test on the purified raffinate solution using Ca(OH)2.

Procedure:
1 Transfer 1500 mL of raffinate to a 2 L reaction vessel. Include agitator, impeller, and baffle.
2 Slowly add 48.5 g of 25 % w/w Ca(OH)2 slurry to pH10.5.
3 Let react at 20 °C for 30 min.
4 Filter the sample through 0.6 μm paper and submit the filtrate for Al, As, Co, Fe, Ni and Zn.
5 Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Purified raffinate solution (from Test No. 19)

Conditions:

Ca(OH)2 addition	Neutralized to pH 10.5	
Temperature	20	°C
Reaction Time	0.5	h
pH	10.5	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	1670 mL	0.2	1.0	0.2	0.1	0.63	8.0	1.6	2.0	0.1	0.9	0.0	42.0
Precipitate	30.7 g	0.07	0.27	2.0	0.03	20.8	0.06	98.4	98.0	99.9	99.1	100.0	58.0
Feed (calc.)	1500 mL	14.3	56	412	6.2	4258	21.2	100	100	100	100	100	100
Feed (assay)		5.6	37	390	1.0	4000	9.4						

Product		Ca	Mg	U	Ra
		(%)	(%)	(μg/g)	(Bq/L)
Precipitate		16	1.8	1.7	0.005

Comments:
Filtrate was very clear.
Filtrate was colouless.
Filtration was fast.
Granular precipitate.

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 17, 1992

Test No. 22

Objective: To conduct a Co-Ni precipitation test on the purified raffinate solution using Na_2CO_3.

Procedure:

1. Transfer 1500 mL of raffinate to a 2 L reaction vessel. Include agitator, impeller, and baffle.
2. Slowly add 93 mL of 200 g/L Na_2CO_3 solution to pH 8.67.
3. Let react at 20 °C for 30 min.
4. Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Zn.
5. Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Purified raffinate solution (from Test No. 19)

Conditions:

Na_2CO_3 addition	Neutralized to pH 8.67	
Temperature	20	°C
Reaction Time	0.5	h
pH	8.67	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	1840 mL	0.2	24.3	5.28	0.1	60	0.1	2.9	52.9	1.7	4.3	1.9	0.6
Precipitate	13.7 g	0.09	0.29	4.2	0.03	41.8	0.12	97.1	47.1	98.3	95.7	98.1	99.4
Feed (calc.)	1500 mL	8.5	56	391	2.9	3891	11.0	100	100	100	100	100	100
Feed (assay)		5.6	37	390	1.0	4000	9.4						

Product		Ca	Mg	U	Ra
		(%)	(%)	(µg/g)	(Bq/L)
Precipitate		4.1	0.68	2.0	0.01

Comments: Filtrate was a light milky colour.
Filtration was fast.
Slimy precipitate.

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	February 17, 1992

Test No. 23

Objective: To conduct a Co-Ni precipitation test on the purified raffinate solution using Na_2CO_3 at 50°C.

Procedure:

1 Transfer 1500 mL of raffinate to a 2 L reaction vessel. Include agitator, impeller, and baffle.
2 Slowly add 93 mL of 200 g/L Na_2CO_3 solution to pH 8.67.
3 Let react at 50 °C for 30 min.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Zn.
5 Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Purified raffinate solution (from Test No. 19) (3rd stage treatment)

Conditions:

Na_2CO_3 addition	Neutralized to pH 8.67	
Temperature	50	°C
Reaction Time	0.5	h
pH	8.67	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	1840 mL	0.2	1.0	0.95	0.05	12.6	0.02	2.9	23.8	0.3	0.6	0.4	0.2
Precipitate	15.5 g	0.08	0.04	3.46	0.10	36.1	0.13	97.1	76.2	99.7	99.4	99.6	99.8
Feed (calc.)	1500 mL	8.51	5.15	359	10.39	3746	13.5	100	100	100	100	100	100
Feed (assay)		5.86	5.96	379	0.54	3900	9.4						

Product		Ca	Mg	U	Ra
		(%)	(%)	(µg/g)	(Bq/L)
Precipitate		4.80	1.64	3.3	0.04

Comments:

Filtrate was clear and colourless.
Filtration was fast.
Waxy precipitate with a few cracks.

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: March 10, 1992

Test No. 24

Objective: To conduct a Ni precipitation test on the Cobalt raffinate solution using Na_2CO_3 at 50°C.

Procedure:

1. Transfer 2000 mL of raffinate to a 3 L reaction vessel. Include agitator, impeller, and baffle.
2. Slowly add 138 mL of 200 g/L Na_2CO_3 solution to pH 8.67.
3. Let react at 50 °C for 30 min.
4. Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni, Ca, Mg and Zn.
5. Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Co raffinate solution (from Test No. SX7)

Conditions:

Na_2CO_3 addition	Neutralized to pH 8.67	
Temperature	50	°C
Reaction Time	0.5	h
pH	8.67	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	2220 mL												
Precipitate	19.1 g	< 0.1	0.05	1.51	<0.05	39.4	0.00						
Feed (calc.)	2000 mL		4.4	144		3762	0.4						
Feed (assay)		<0.10	4.8	128	<0.02	3960	0.02						

Product		Ca	Mg	U	Ra
		(%)	(%)	(µg/g)	(Bq/L)
Precipitate		4.43	2.28	0.5	0.02

Additional Analyses: Co raffinate feed
468 mg/L Ca
516 mg/L Mg

Comments: Filtrate was clear and colourless.
Filtration was fast.
Waxy precipitate with a few cracks.

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: March 10, 1992

Test No. 25

Objective: To conduct a Co precipitation test on the Cobalt strip liquor using Na2CO3 at 50°C.

Procedure:
1 Transfer 130 mL of strip liquor and 370 mL water to a 500 mL beaker.
2 Slowly add 33 mL of 200 g/L Na2CO3 solution to pH 8.67.
3 Let react at 50 °C for 30 min.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni, Ca, Mg and Zn.
5 Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Co strip liquor (from Test No. SX7)

Conditions:

Na2CO3 addition	Neutralized to pH 8.67	
Temperature	50	°C
Reaction Time	0.5	h
pH	8.67	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	620 mL												
Precipitate	4.4 g	0.30	0.02	40.20	0.05	1.9	0.52						
Feed (calc.)	130 mL	102	7	13606	17	643	176						
Feed (assay)		21	<10	13750	1.4	639	185						

Product		Ca (%)	Mg (%)	U (µg/g)	Ra (Bq/L)
Precipitate		1.42	1.78	1.3	0.08

Additional Analyses: Co strip liquor feed
596 mg/L Ca
1120 mg/L Mg

Comments: Filtrate was clear and colourless.
Filtration was very fast.
Purple (mauve) precipitate.

APPENDIX C: Test Details: Solvent Extraction

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	February 24, 1992

Test No. **SX1**

Objective: To generate the pH extraction isotherm for Co and Ni using the purified raffinate solution and Cyanex 272.

Procedure:
1 Quantitatively transfer 150 mL of SX feed to a 500 mL mixer vessel.
2 Stir the aqueous phase at 1000 rpm and slowly add 150 mL of fresh organic.
3 Control the pH of the aqueous continuous dispersion to various set pionts.
4 Allow the dispersion to coalesce and settle. Separate the two phases.
5 Filter the raffinate through Whatman No. 42 paper to remove entrained organic.
6 Filter the organic through Whatman No. 1PS paper to remove entrained raffinate.
7 Submit the loaded organics, raffinates and a sample of the SX aqueous feed for analyses.

Feed:

SX Feed
Purified raffinate solution

Ni	3900 mg/L
Co	379 mg/L
pH	4.0

Organic Feed
0.5 M Cyanex 272 in Isopar M

Cyanex 272	16 % v/v
Isopar M	84 % v/v

Conditions:

Phase ratio	1/1
Contact Time	5 min.
Temperature	20 °C

Data:

pH	Organic		Aqueous		Distribution Coefficient	Co Extracted (%)	Feed Calc. (mg/L)
	Vol. (mL)	Co (mg/L)	Vol. (mL)	Co (mg/L)			
4.0	150	89.2	150.1	301	0.3	22.9	390
4.5	150	300	150.3	91.9	3.3	76.6	392
5.0	150	365	150.6	19.6	19	94.9	385
5.5	150	395	151.0	3.48	114	99.1	399
6.0	150	365	152.0	2.42	151	99.3	367
Feed	-	-	150.0	379	-	-	-

pH	Organic		Aqueous		Distribution Coefficient	Ni Extracted (%)	Feed Calc. (mg/L)
	Vol. (mL)	Ni (mg/L)	Vol. (mL)	Ni (mg/L)			
4.0	150	2.97	150.1	3900	0.0	0.1	3906
4.5	150	13.6	150.3	3900	0.0	0.3	3921
5.0	150	65.1	150.6	3800	0.0	1.7	3880
5.5	150	385	151.0	3440	0.1	10.1	3848
6.0	150	1430	152.0	2370	0.6	37.6	3832
Feed	-	-	150.0	3900	-	-	-

Observations: Good phase disengagement times of 0.5 to 1.25 min. Clear and clean interphases. Green raffinate and deep blue loaded organic.

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 24, 1992

Test No. **SX2**

Objective: To generate the pH extraction isotherm for Co and Ni using the purified raffinate solution and Cyanex 302.

Procedure:

1 Quantitatively transfer 150 mL of SX feed to a 500 mL mixer vessel.
2 Stir the aqueous phase at 1000 rpm and slowly add 150 mL of fresh organic.
3 Control the pH of the aqueous continuous dispersion to various set pionts.
4 Allow the dispersion to coalesce and settle. Separate the two phases.
5 Filter the raffinate through Whatman No. 42 paper to remove entrained organic.
6 Filter the organic through Whatman No. 1PS paper to remove entrained raffinate.
7 Submit the loaded organics, raffinates and a sample of the SX aqueous feed for analyses.

Feed:

SX Feed
Purified raffinate solution

Ni	3900 mg/L
Co	379 mg/L
pH	4.0

Organic Feed
0.5 M Cyanex 302 in Isopar M

Cyanex 302	16 % v/v
Isopar M	84 % v/v

Conditions:

Phase ratio	1/1
Contact Time	5 min.
Temperature	20 °C

Data:

pH	Organic		Aqueous		Distribution Coefficient	Co Extracted	Feed Calc.
	Vol.	Co	Vol.	Co			
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
2.0	150	3.68	150.0	374	0.0	1.0	378
2.5	150	12.8	150.0	353	0.0	3.5	366
3.0	150	89.8	150.2	270	0.3	25.0	360
3.5	150	275	150.3	93.3	2.9	74.7	368
4.0	150	309	150.4	14.9	21	95.4	324
Feed	-	-	150.0	379	-	-	-

pH	Organic		Aqueous		Distribution Coefficient	Ni Extracted	Feed Calc.
	Vol.	Ni	Vol.	Ni			
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
2.0	150	88.4	150.0	3770	0.0	2.3	3858
2.5	150	88.4	150.0	3700	0.0	2.3	3788
3.0	150	97.2	150.2	3540	0.0	2.7	3641
3.5	150	100	150.3	3290	0.0	2.9	3397
4.0	150	113	150.4	3280	0.0	3.3	3402
Feed	-	-	150.0	3900	-	-	-

Observations: **Good phase disengagement times of 0.5 to 1.25 min. Clear and clean interphases. Green raffinate and deep blue loaded organic.**

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 24, 1992

Test No. **SX3**

Objective: To generate the pH extraction isotherm for Co and Ni using the purified raffinate solution and Ionquest 801.

Procedure:
1 Quantitatively transfer 150 mL of SX feed to a 500 mL mixer vessel.
2 Stir the aqueous phase at 1000 rpm and slowly add 150 mL of fresh organic.
3 Control the pH of the aqueous continuous dispersion to various set pionts.
4 Allow the dispersion to coalesce and settle. Separate the two phases.
5 Filter the raffinate through Whatman No. 42 paper to remove entrained organic.
6 Filter the organic through Whatman No. 1PS paper to remove entrained raffinate.
7 Submit the loaded organics, raffinates and a sample of the SX aqueous feed for analyses.

Feed:

SX Feed		Organic Feed	
Purified raffinate solution		0.5 M Ionquest 801 in Isopar M	
Ni	3900 mg/L		
Co	379 mg/L	Ionquest 801	16 % v/v
pH	4.0	Isopar M	84 % v/v

Conditions:

Phase ratio	1/1
Contact Time	5 min.
Temperature	20 °C

Data:

pH	Organic		Aqueous		Distribution Coefficient	Co Extracted	Feed Calc.
	Vol.	Co	Vol.	Co			
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
3.0	150	15.1	150.2	346	0.0	4.2	361
3.5	150	87	150.5	269	0.3	24.4	357
4.0	150	260	150.8	111	2	70.1	372
4.5	150	365	151.2	34.9	10	91.3	400
5.0	150	405	151.8	9.76	41	97.6	415
Feed	-	-	150.0	379	-	-	-

pH	Organic		Aqueous		Distribution Coefficient	Ni Extracted	Feed Calc.
	Vol.	Ni	Vol.	Ni			
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
3.0	150	11.2	150.2	3750	0.0	0.3	3765
3.5	150	260	150.5	3610	0.1	6.7	3881
4.0	150	572	150.8	3290	0.2	14.8	3880
4.5	150	825	151.2	3010	0.3	21.5	3859
5.0	150	1720	151.8	2170	0.8	44.2	3916
Feed	-	-	150.0	3900	-	-	-

Observations: Good phase disengagement times of 0.5 to 1.25 min. Clear and clean interphases. Green raffinate and deep blue loaded organic.

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: February 27, 1992

Test No. SX4

Objective: To generate the extraction distribution isotherm for Co and Ni using the purified raffinate solution and Cyanex 272.

Procedure:
1 Quantitatively transfer a volume of SX feed to a 500 mL mixer vessel.
2 Stir the aqueous phase at 1000 rpm and slowly add a volume of fresh organic.
3 Control the pH of the aqueous continuous dispersion to pH 4.5.
4 Allow the dispersion to coalesce and settle. Separate the two phases.
5 Filter the raffinate through Whatman No. 42 paper to remove entrained organic.
6 Filter the organic through Whatman No. 1PS paper to remove entrained raffinate.
7 Submit the loaded organics, raffinates and a sample of the SX aqueous feed for analyses.

Feed:

SX Feed		Organic Feed	
Purified raffinate solution		0.5 M Cyanex 272 in Isopar M	
Ni	3900 mg/L		
Co	379 mg/L	Cyanex 272	16 % v/v
pH	4.0	Isopar M	84 % v/v

Conditions:

Phase ratio	various
Contact Time	5 min.
Temperature	20 °C
pH	4.5

Data:

O/A	Organic		Aqueous		Distribution	Co	Feed
ratio	Vol.	Co	Vol.	Co	Coefficient	Extracted	Calc.
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
2/1	200	170	100	42.3	4.0	88.9	382
1/1	150	300	150	86.3	3.5	77.7	386
1/2	100	560	200	138	4.1	67.0	418
1/3	75	620	225	166	3.7	55.5	373
1/5	50	975	250	208	4.7	48.4	403
1/10	25	1010	250	295	3.4	25.5	396
Feed	-	-	-	379	-	-	-

O/A	Organic		Aqueous		Distribution	Ni	Feed
ratio	Vol.	Ni	Vol.	Ni	Coefficient	Extracted	Calc.
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
2/1	200	18.3	100	3840	0.0	0.9	3877
1/1	150	15.2	150	4000	0.0	0.4	4015
1/2	100	14.2	200	3930	0.0	0.2	3937
1/3	75	13.9	225	3810	0.0	0.1	3815
1/5	50	14.3	250	3890	0.0	0.1	3893
1/10	25	11.2	250	3930	0.0	0.0	3931
Feed	-	-	-	3900	-	-	-

Observations: Good phase disengagement times of 0.5 to 1.25 min. Clear and clean interphases. Green raffinate and deep blue loaded organic.

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: March 5, 1992

Test No. SX5

Objective: To prepare a loaded organic sample for a stripping test.

Procedure:

1 Transfer 12L of SX feed to a 20 L mixer vessel.
2 Stir the aqueous phase at 1000 rpm and slowly add 1.2 L of organic.
3 Control the pH of the aqueous continuous dispersion to pH 4.5.
4 Allow the dispersion to coalesce and settle. Separate the two phases.
5 Repeat steps 1 to 4 three times to build up the Co concentration in the organic phase.
6 Filter the organic through Whatman No. 1PS paper to remove entrained raffinate.
7 Submit the loaded organics, raffinates and SX feed for analyses.

Feed:

SX Feed
Purified raffinate solution

Ni	3900 mg/L
Co	379 mg/L
pH	4.0

Organic Feed
0.5 M Cyanex 272 in Isopar M

Cyanex 272	16 % v/v
Isopar M	84 % v/v

Conditions:

O/A ratio	1/10
Contact Time	5 min.
Temperature	20 °C
pH	4.5

Data:

Contact	Organic		Aqueous		Distribution	Co	Feed
No	Vol.	Co	Vol.	Co	Coefficient	Extracted	Calc.
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
1	1200	860	12000	293	2.9	22.7	379
2	1200	930	12000	357			
3	1200	940	12000	369			
Feed	-	-	-	379	-	-	-

Contact	Organic		Aqueous		Distribution	Ni	Feed
No	Vol.	Ni	Vol.	Ni	Coefficient	Extracted	Calc.
	(mL)	(mg/L)	(mL)	(mg/L)		(%)	(mg/L)
1	1200	4.0	12000	3900	0.0	0.0	3900
2	1200	6.0	12000	3830			
3	1200	8.4	12000	3710			
Feed	-	-	-	3900	-	-	-

Observations: Good phase disengagement. Clear and clean interphases.
Green raffinate and deep blue loaded organic.

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: March 6, 1992

Test No. **SX6**

Objective: To generate the strip isotherm for Co and Ni using a loaded organic and 50 g/L H2SO4 strip solution.

Procedure:
1 Quantitatively transfer a volume of loaded organic and strip solution to a mixer.
2 Contact the phases for 3 minutes.
3 Allow the dispersion to coalesce and settle. Separate the two phases.
4 Filter the raffinate through Whatman No. 42 paper to remove entrained organic.
5 Filter the organic through Whatman No. 1PS paper to remove entrained raffinate.
6 Submit the stripped organics, strip liquors and the loaded organic for analyses.

Feed:

Strip Solution	Loaded Organic Feed
50 g/L H2SO4	0.5 M Cyanex 272 in Isopar M
	940 mg/L Co
	8.4 mg/L Ni

Conditions:
Phase ratio Various
Contact Time 6 min.
Temperature 20 °C

Data:

O/A Ratio	Organic Vol. (mL)	Organic Co (mg/L)	Aqueous Vol. (mL)	Aqueous Co (mg/L)	pH	Distribution Coefficient	Co Stripped (%)	Feed Calc. (mg/L)
20/1	300	16.0	15.0	18750	2.25	1172	100.0	954
15/1	225	3.5	15.0	13940	1.59	3949	100.0	933
10/1	150	0.9	15.0	9430	1.26	10478	100.0	944
5/1	75	0.6	15.0	4060	0.87	6656	100.0	813
2/1	30	0.5	15.0	1780	0.71	3870	100.0	890
1/1	15	0.2	15.0	940	0.68	4700	100.0	940
Feed	-	940	-	-	-	-	-	-

O/A Ratio	Organic Vol. (mL)	Organic Ni (mg/L)	Aqueous Vol. (mL)	Aqueous Ni (mg/L)	pH	Distribution Coefficient	Ni Stripped (%)	Feed Calc. (mg/L)
20/1	300	0.1	15.0	175	2.25	1750	100.0	8.9
15/1	225	0.1	15.0	118	1.59	1180	100.0	8.0
10/1	150	0.1	15.0	79	1.26	786	100.0	8.0
5/1	75	0.1	15.0	37	0.87	371	99.9	7.5
2/1	30	0.1	15.0	16	0.71	160	99.7	8.1
1/1	15	0.1	15.0	8.8	0.68	88	98.9	8.9
Feed	-	8.4	-	-	-	-	-	-

Observations: Fast phase disengagement times. Pink strip liquors. Small amount of crud at interphase. 6 minute mass transfer time was required.

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	March 9, 1992

Test No. **SX7**

Objective: To prepare a strip liquor and Co raffinate sample for Co and Ni precipitation tests.

Procedure:

1 Prepare the raffinate sample by processing the SX feed through a continuous mixer settler.
2 Set the SX feed flowrate to 600 mL/min and the organic to 100 mL/min.
3 Control the pH of the aqueous continuous dispersion to pH 4.5.
4 Composite of all loaded organics that were contacted at an equilibrium pH 4.5
5 Prepare a strip liquor sample by contacting the loaded organic with 50 g/L H2SO4 at an O/A ratio of 30/1. Carry out the contact for 6 min.

Feed:

SX Feed		Strip Solution	Organic Feed
Purified raffinate solution		50 g/L H2SO4	0.5 M Cyanex 272 in Isopar M
Ni	3900 mg/L		Composite of all loaded organic
Co	379 mg/L		samples contacted at pH 4.5
pH	4.0		

Conditions:

Extraction		Stripping	
O/A ratio	1/6	O/A ratio	30/1
Contact Time	3 min.	Contact Time	6 min.
Temperature	20 °C	Temperature	20 °C
pH	4.5	H2SO4	50 g/L

Data:

Analyses (mg/L)

	Al	As	Ca	Co	Fe	Mg	Ni	Zn
SX Feed	5.86	5.96	520	379	0.54	520	3900	9.4
Co Raffinate	<0.10	4.81	468	128	<0.02	512	3960	0.02
Strip Liquor	20.9	<10	596	13750	1.36	1120	639	185
Loaded Organic	11.4	0.67	91	550	1.6	45	17	27

Observations: Good phase disengagement. Clear and clean interphases.
Green raffinate and deep blue loaded organic.

LAKEFIELD RESEARCH
A Division of Falconbridge Limited
Lakefield, Ontario
April 2nd, 1992/ jm

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An investigation of

THE RECOVERY OF NICKEL AND COBALT

from Midwest Uranium Raffinate

submitted by

MIDWEST JOINT VENTURES

Progress Report No. 2

(Flowsheet Development)

Project No. L.R. 4234

NOTE:

This report refers to the samples as received.

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LAKEFIELD RESEARCH
A DIVISION OF FALCONBRIDGE LIMITED
August 4th,1992

ABSTRACT

A test program was conducted on Midwest Joint Venture uranium raffinate for the recovery of cobalt and nickel.

The raffinate was purified by a two-stage precipitation procedure for the removal of arsenic, radium and other metals prior to carbonate precipitation of cobalt and nickel.

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INTRODUCTION

Previous testwork (Progress Report No. 1, LR 4234) has shown that cobalt and nickel can be recovered from Midwest uranium raffinate. The results from the first phase of work are summarized as follows.

- The addition of hydrogen peroxide to the raffinate is required to complete the precipitation of iron and arsenic.
- First stage precipitation must be conducted between pH 4.5 to 5.0 with the addition of ferric sulphate at >1/1 Fe^{+3}/As molar ratio.
- Co-precipitated cobalt and nickel from stage precipitation is recovered by repulping or washing the precipitate in pH 3.0 to 3.5 sulphuric acid.
- The removal of radium by treatment with barium chloride is very effective.
- Second stage precipitation must be conducted between pH 5.0 to 6.0 with the addition of ferric sulphate at $\geq$ 4/1 Fe^{+3}/As molar ratio. The second stage precipitate must be recycled to the raffinate feed for recovery of co-precipitated metals.
- Cobalt and nickel are recovered from purified raffinate solution by bulk precipitation with Na_2CO_3 at 50°C. Precipitation at an elevated temperature is required to improve filtration characteristics.

This report documents the Hydrometallurgical test program conducted during the period from April 29 to July 20, 1992 on a uranium raffinate sample. The test program included preparation of raffinate, locked cycle tests, and a large scale test to produce slurries for filtration and thickening tests.

LAKEFIELD RESEARCH

for Cesar Joe Ferron, Ph.D.
Manager - Hydrometallurgy

Steve Webster

Steven Webster
Metallurgist

Experimental Work by: Warren Reishus

SUMMARY

1. Preparation of Uranium Raffinate

Midwest leach solution was prepared by leaching two 50 kg batches of a blend of pilot plant composite No. 2 and Midwest high grade ore in a 200 L Pfaudler autoclave. The leaches were conducted under the following conditions:

Grind size	100% - 35 mesh
Pulp density	35% solids
Acid addition	216 kg H_2SO_4/t
Temperature	60°C
Time	4 h
Oxygen overpressure	475 kPa
Oxygen off gas	1 - 2 L/min

The leach discharges from the two leaches were combined and a sample of the leach solution was analysed to contain the following:

20.6 g/L U
7.9 g/L Ni
0.98 g/L Co

The leach slurry was diluted, thickened and decanted several times to recover most of the leached metals. The partially washed residue was neutralized and stored for final disposal. The leach and decant solutions were combined and clarified by filtering with cellulose filter aid producing 625 L of SX feed.

A raffinate was prepared from the SX feed solution by extracting the uranium with Alamine 336. A flowsheet illustrating the SX procedure is given in Figure 1.

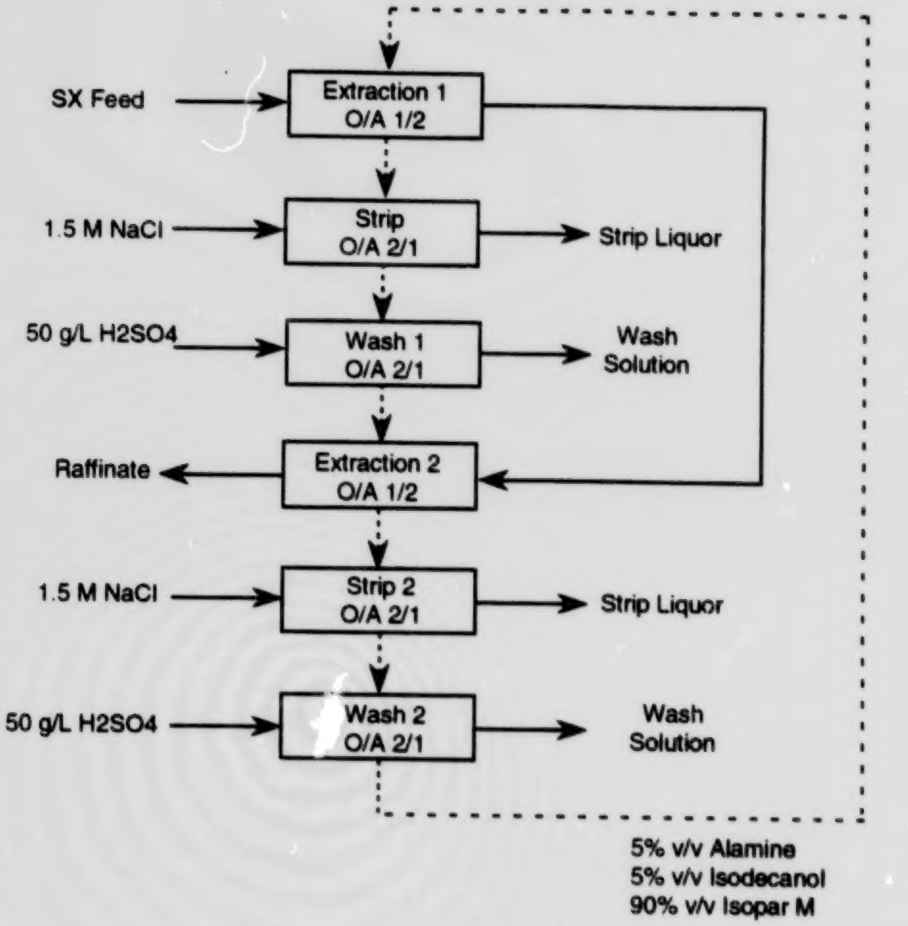
SX Feed
Extraction 1
O/A 1/2
1.5 M NaCl
Strip
O/A 2/1
Strip Liquor
50 g/L H2SO4
Wash 1
O/A 2/1
Wash
Solution
Raffinate
Extraction 2
O/A 1/2
1.5 M NaCl
Strip 2
O/A 2/1
Strip Liquor
50 g/L H2SO4
Wash 2
O/A 2/1
Wash
Solution
5% v/v Alamine
5% v/v Isodecanol
90% v/v Isopar M

Figure 1: Flowsheet Illustrating the Procedure for the Preparation of Raffinate

2. Locked Cycle Tests

Two locked cycle tests were conducted for six cycles to simulate a continuous operation for the evaluation of the flowsheet shown in Figure 2. The tests were conducted with the same raffinate as used in Progress Report No. 1, LR 4234.

Test No. 26 was conducted with second stage (residual precipitation) at pH 5 and Test No. 27 with pH 6.

Cycles 1 to 3 were conducted with a low wash ratio and cycles 4 to 6 with a high wash ratio. The results are summarized in Table 1 for the recovery of co-precipitated metals from first stage precipitate (arsenic precipitation).

Summary

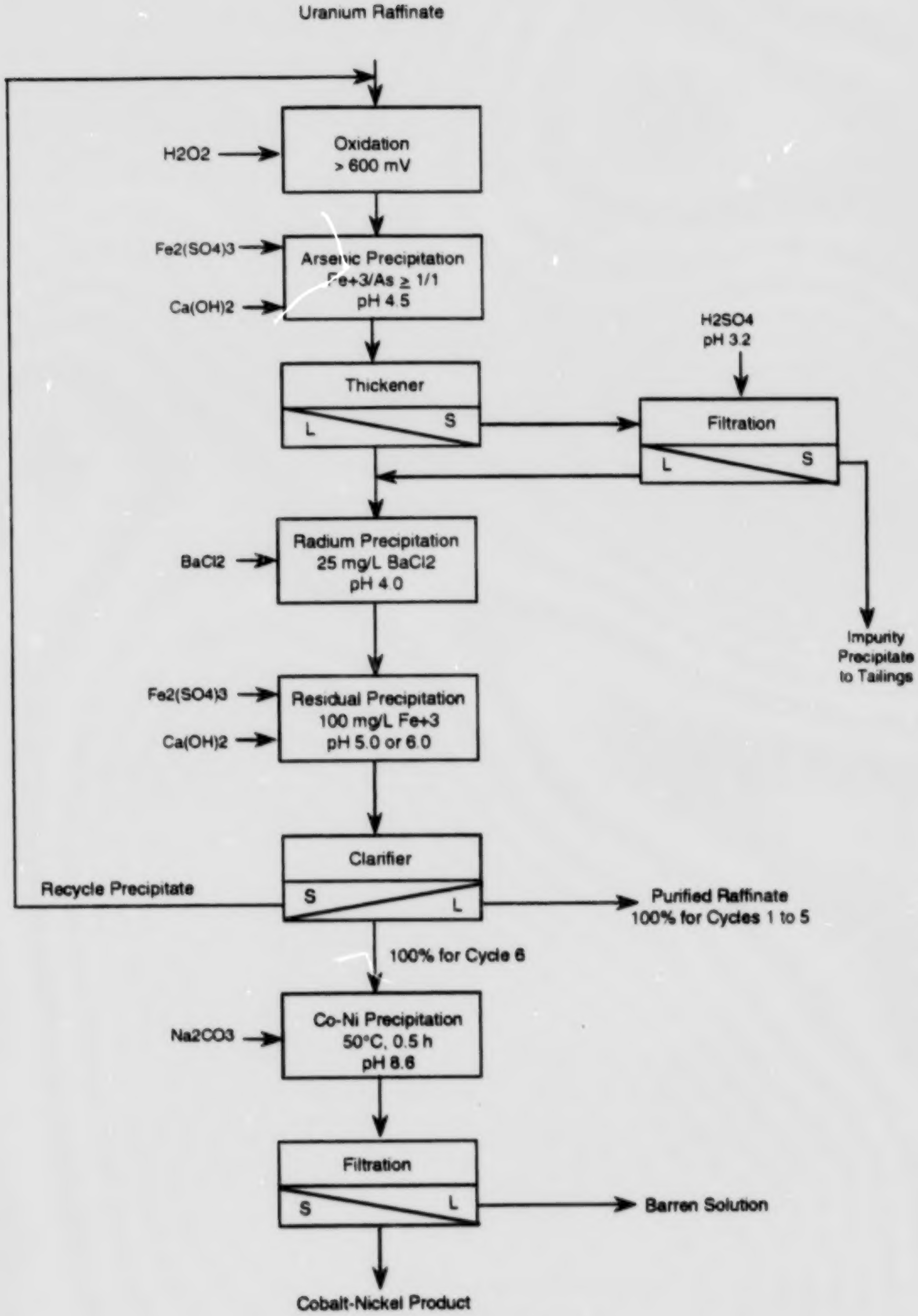
Uranium Raffinate
H2O2
Oxidation
> 600 mV
Fe2(SO4)3
Ca(OH)2
Arsenic Precipitation
Fe+3/As ≥ 1/1
pH 4.5
H2SO4
pH 3.2
Thickener
L
S
Filtration
L
S
Radium Precipitation
25 mg/L BaCl2
pH 4.0
BaCl2
Impurity
Precipitate
to Tailings
Fe2(SO4)3
Ca(OH)2
Residual Precipitation
100 mg/L Fe+3
pH 5.0 or 6.0
Clarifier
Recycle Precipitate
S
L
Purified Raffinate
100% for Cycles 1 to 5
100% for Cycle 6
Na2CO3
Co-Ni Precipitation
50°C, 0.5 h
pH 8.6
Filtration
S
L
Barren Solution
Cobalt-Nickel Product

Figure 2: Flowsheet for Raffinate Purification and Cobalt-Nickel Precipitation.

Table 1: Summary of Locked Cycle Purification Tests

Test No.	Cycle No.	Wash Ratio Wash Vol/Bed Vol.	2nd Stage pH	Percentage Removed from Solution (%)					
				Al	As	Co	Fe	Ni	Zn
26	3	0.6/1	5.0	99.2	100.0	12.5	98.5	11.1	0.0
26	6	2.0/1	5.0	99.2	98.3	7.9	98.6	6.2	0.0
27	3	0.6/1	6.0	99.9	100.0	13.8	100.0	13.2	12.4
27	6	2.1/1	6.0	99.9	99.0	12.2	99.0	10.4	19.21

At a low wash ratio, 12.5 to 13.8% of the cobalt and 11.1 to 13.2% of the nickel were removed along with the first stage precipitate. However, first stage precipitation was very effective in removing aluminum, arsenic and iron.

A high wash ratio of two displacement volumes improved the recovery of cobalt and nickel. Only 7.9 to 12.2% of the cobalt and 6.2 to 10.4% of the nickel were lost to the first stage precipitate.

The effect of second stage pH is also summarized in Table 1. At the higher pH of 6, it was more effective in the removal of impurities, including up to 19% of the zinc, however, at the expense of cobalt and nickel.

It is shown that changing the operating parameters, such as second stage pH, wash ratio, or even the pH of the wash solution, can produce a desired amount of purification with lower losses of the cobalt and nickel. Test No. 27, Cycle 3, for instance produced high purity (essentially 100% removal of impurities) but only recovered 86% of the cobalt and nickel. Test No. 26, cycle 6 produced a marginally less pure solution and recovered 92% of the cobalt and 94% of the nickel.

At the end of the six cycles, cobalt and nickel were co-precipitated from the purified raffinate with sodium carbonate. The solution was heated to 50°C and a 200 g/L Na_2CO_3 solution was added to a constant pH of 8.6. After a 30 minute reaction period the precipitate was filtered and analysed as shown in Table 2. Test details are provided in Appendix B.

Table 2: Analyses of Cobalt-Nickel Carbonate Product

Element	Analyses (%)	
	Test No. 26	Test No. 27
Al	0.1	0.1
As	0.6	0.3
Ca	5.7	6.2
Co	3.0	3.1
Fe	0.4	0.2
Mg	2.0	1.9
Ni	31.2	30.9
Zn	0.2	0.3
U	0.00017	0.00008
Ra^{226}	0.02 Bq/g	0.02 Bq/g

The cobalt-nickel products contained 3% cobalt and 31% nickel which would make an ideal secondary feed material to a smelter. Apparently the zinc content of the material would prevent it from being processed directly at a refinery. The products were extremely low in uranium and radium. The radium level was 0.02 Bq/g, fifty times lower than the maximum allowable limit for gypsum wall board. The products contained 0.3 to 0.6% arsenic which is not a problem for a smelter.

3. Large Scale Co-Ni Recovery Test

A 625 L batch of raffinate was treated semi-continuous for the precipitation of impurities followed by cobalt-nickel precipitation. Each unit operation was done continuously by pumping the raffinate and the various reagents, into a 20L agitated reaction vessel. The products from the reaction vessel flowed by gravity into a 900L conical thickening tank. A diagram showing the apparatus is given in Figure 3. A flowsheet detailing the procedure is given in Figure 4.

Samples of first stage, second stage and cobalt-nickel precipitated slurries were taken for thickening and filtration testing. The results are provided in a separate report by Bill Stone of EIMCO Process Equipment

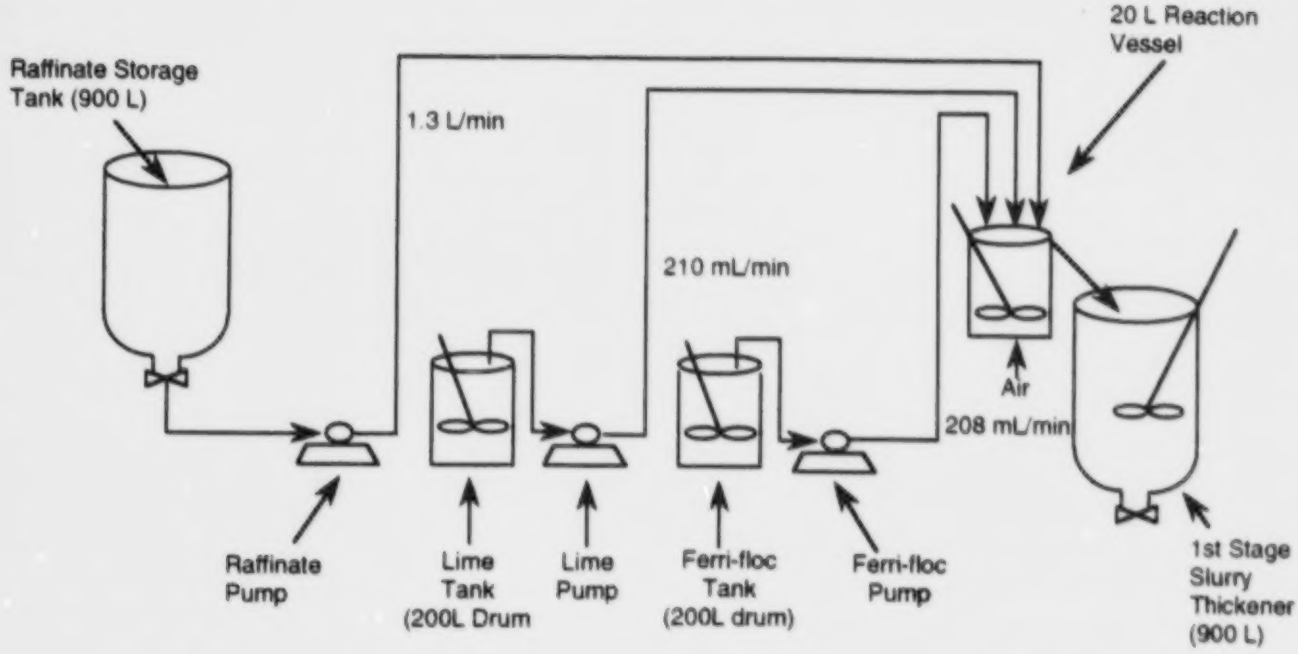
20 L Reaction Vessel
Raffinate Storage Tank (900 L)
1.3 L/min
210 mL/min
Air
208 mL/min
Raffinate Pump
Lime Tank (200L Drum
Lime Pump
Ferri-floc Tank (200L drum)
Ferri-floc Pump
1st Stage Slurry Thickener (900 L)

Figure 3: Diagram Detailing the Semi-Continuous Apparatus

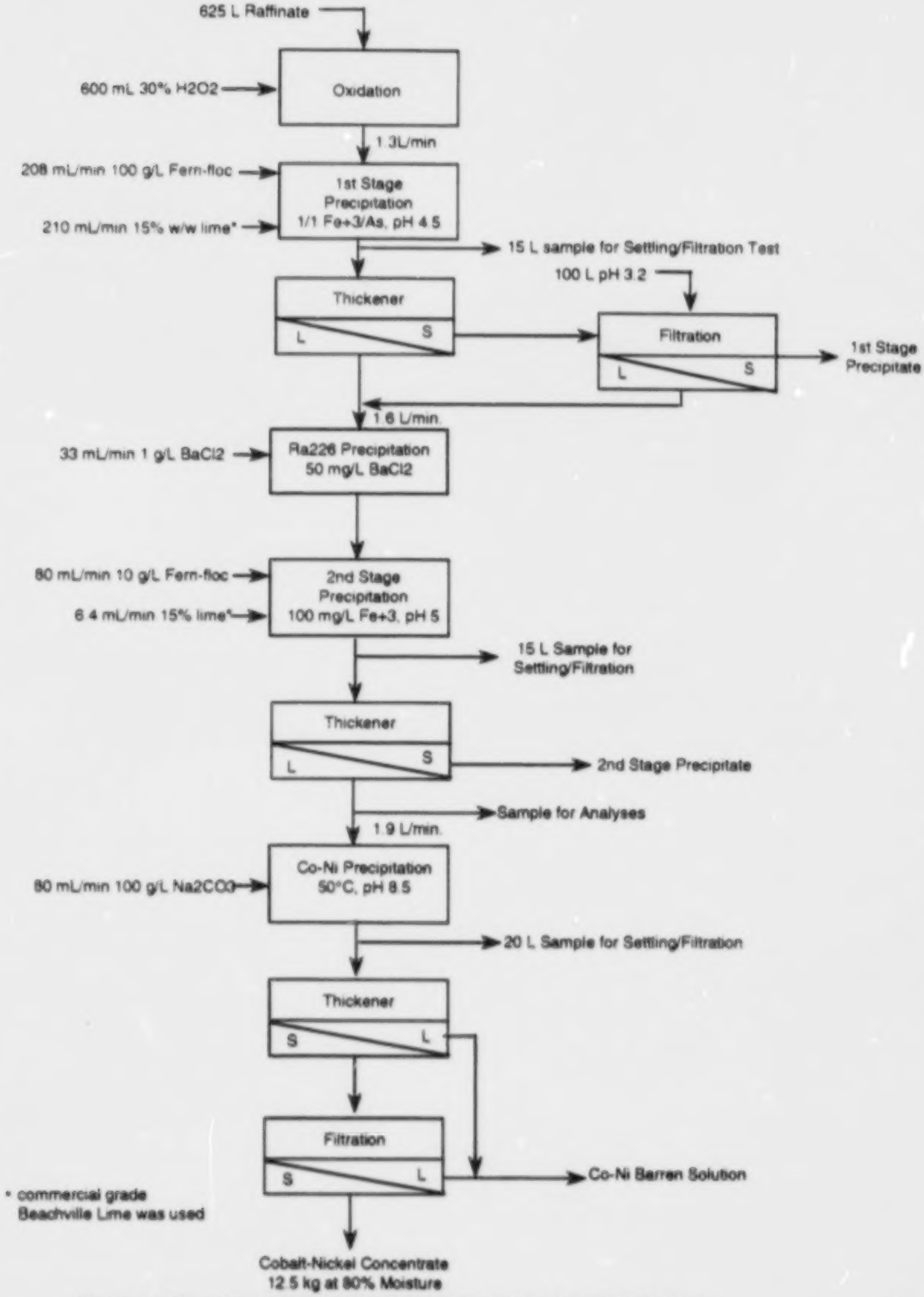
625 L Raffinate
600 mL 30% H2O2
Oxidation
1.3L/min
208 mL/min 100 g/L Fern-floc
210 mL/min 15% w/w lime*
1st Stage Precipitation 1/1 Fe+3/As, pH 4.5
15 L sample for Settling/Filtration Test
100 L pH 3.2
Thickener
L
S
Filtration
L
S
1st Stage Precipitate
1.6 L/min.
33 mL/min 1 g/L BaCl2
Ra226 Precipitation 50 mg/L BaCl2
80 mL/min 10 g/L Fern-floc
6.4 mL/min 15% lime*
2nd Stage Precipitation 100 mg/L Fe+3, pH 5
15 L Sample for Settling/Filtration
Thickener
L
S
2nd Stage Precipitate
Sample for Analyses
1.9 L/min.
80 mL/min 100 g/L Na2CO3
Co-Ni Precipitation 50°C, pH 8.5
20 L Sample for Settling/Filtration
Thickener
S
L
Filtration
S
L
Co-Ni Barren Solution
* commercial grade Beachville Lime was used
Cobalt-Nickel Concentrate 12.5 kg at 80% Moisture

Figure 4: Flowsheet Detailing the Procedure for the Large Scale Test

A sample of the purified raffinate solution (after second stage precipitation) was analysed and the results are compared to the raffinate feed in Table 3.

Table 3: Analyses Comparing the Raffinate and Purified Raffinate Solution

Element	1st Stage Precipitate (%)	2nd Stage Precipitate (%)	Raffinate (mg/L)	1st Stage Solution (mg/L)	Purified Raffinate 2nd Stage Solution (mg/L)
Al	1.93	0.64	1290	0.80	0.56
As	4.81	0.37	4170	0.63	0.49
Co	0.074	0.18	254	172	159
Fe	6.71	31.2	1320	1.81	1.66
Ni	0.69	2.18	2320	1360	1250
U	0.023	0.009	17.2	<1	<1
Zn	0.11	0.27	101	39	33
Ra^{226}	-	-	-	-	0.16 Bq/L*

* The result was reported after 24 hours. The actual result after 1 week would be lower than 0.16 Bq/L.

The results in Table 3 show that the pretreatment procedure was very effective for the removal of all impurities except zinc.

Analyses on the cobalt-nickel carbonate precipitate are given in Table 4.

Table 4: Analyses on the Cobalt-Nickel Product

Element	Analyses (%)
Al	< 0.10
As	0.004
Ca	10.5
Co	2.26
Fe	0.029
Mg	1.06
Ni	18.6
U	0.0006
Zn	0.64
Ra226	0.03 Bq/L

4. Small Scale Cu-Ni Recover Test

The test was conducted with a mixture of raffinate and SX feed to determine if the pretreatment procedure could handle a raffinate feed high in uranium. The feed contained 697 mg/L U which is well above any anticipated concentration that would be caused by an upset in uranium solvent extraction. The procedure and results are shown in Figure 5.

The final cobalt-nickel concentrate contained 28.2% Ni and 2.58% Co. Arsenic was low at 0.07% As, however it did contain uranium at 0.11% U.

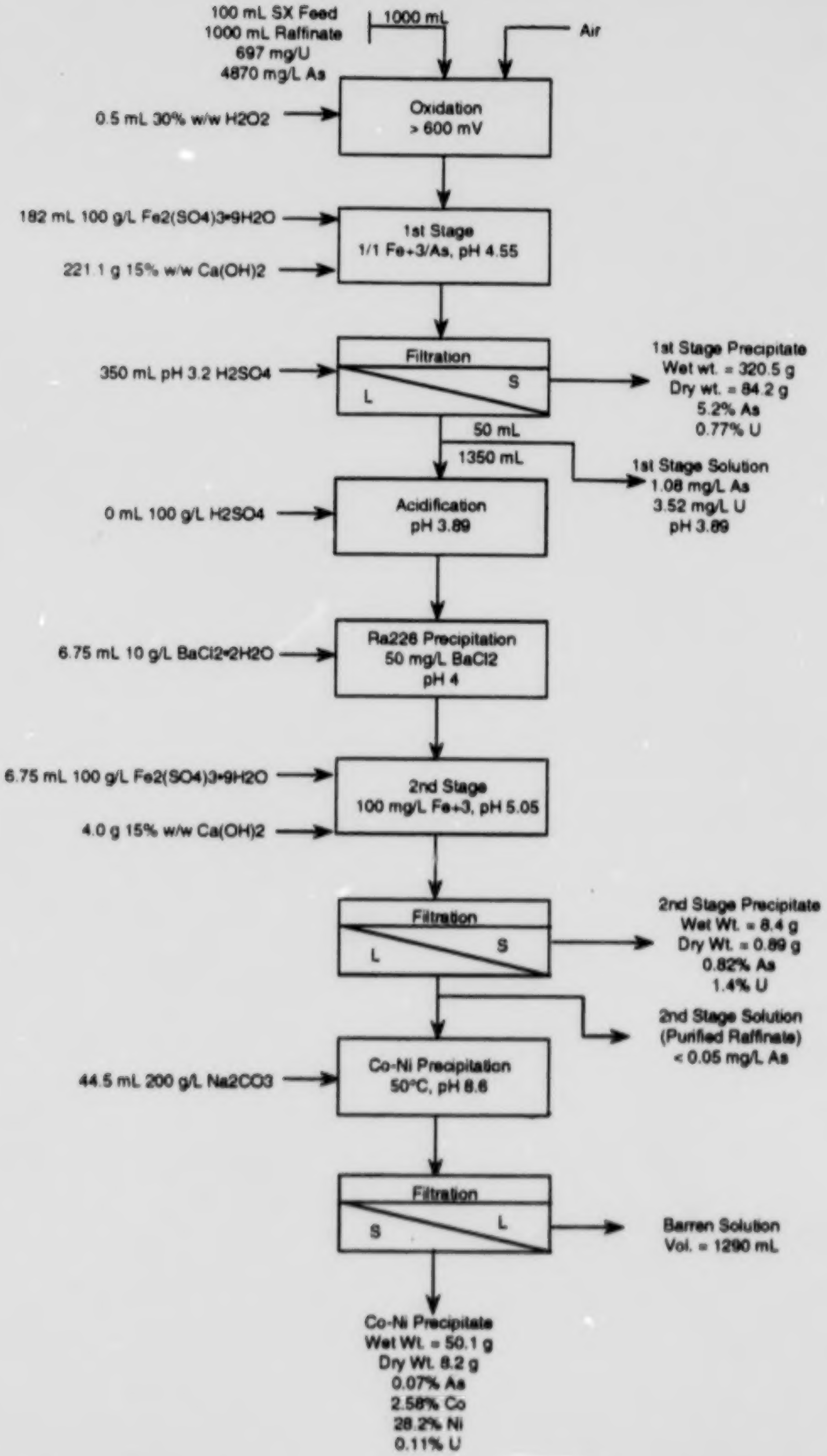
100 mL SX Feed
1000 mL Raffinate
697 mg/U
4870 mg/L As
1000 mL
Air
0.5 mL 30% w/w H2O2
Oxidation
> 600 mV
182 mL 100 g/L Fe2(SO4)3•9H2O
221.1 g 15% w/w Ca(OH)2
1st Stage
1/1 Fe+3/As, pH 4.55
350 mL pH 3.2 H2SO4
Filtration
L
S
1st Stage Precipitate
Wet wt. = 320.5 g
Dry wt. = 84.2 g
5.2% As
0.77% U
50 mL
1350 mL
1st Stage Solution
1.08 mg/L As
3.52 mg/L U
pH 3.89
0 mL 100 g/L H2SO4
Acidification
pH 3.89
6.75 mL 10 g/L BaCl2•2H2O
Ra226 Precipitation
50 mg/L BaCl2
pH 4
6.75 mL 100 g/L Fe2(SO4)3•9H2O
4.0 g 15% w/w Ca(OH)2
2nd Stage
100 mg/L Fe+3, pH 5.05
Filtration
L
S
2nd Stage Precipitate
Wet Wt. = 8.4 g
Dry Wt. = 0.89 g
0.82% As
1.4% U
2nd Stage Solution
(Purified Raffinate)
< 0.05 mg/L As
44.5 mL 200 g/L Na2CO3
Co-Ni Precipitation
50°C, pH 8.6
Filtration
S
L
Barren Solution
Vol. = 1290 mL
Co-Ni Precipitate
Wet Wt. = 50.1 g
Dry Wt. 8.2 g
0.07% As
2.58% Co
28.2% Ni
0.11% U

Figure 5: Flowsheet Detailing Procedure for Test to Simulate an Up-set Condition

APPENDIX A: Locked Cycle Purification Tests

Project No.	4234	**Technician**	Warren Reishus
Client:	Midwest Joint Ventures	**Date:**	May 20, 1992

Test No. 26

		Cycle 1	Cycle 2	Cycle 3
Uranium Raffinate Feed				
Volume	(mL)	1000	1000	1000
Al	(mg/L)	2100	2100	2100
As	(mg/L)	5300	5300	5300
Co	(mg/L)	538	538	538
Fe	(mg/L)	69	69	69
Ni	(mg/L)	5400	5400	5400
Zn	(mg/L)	8.0	8.0	8.0
Oxidation				
Wt of 2nd stage precipitate	(g)	0.0	4.6	3.6
Wt of 30 % w/w H2O2	(g)	2.0	1.7	1.7
1st Stage Precipitation				
Volume of 20 g/L Fe+3	(mL)	210	210	210
Wt of 15 % w/w Ca(OH)2	(g)	209.5	197.3	185.9
Fe+3 / As molar ratio		1/1	1/1	1/1
pH		4.5	4.5	4.5
1st Stage Filtration & Washing				
Volume of pH 3.2 H2SO4	(mL)	150	150	150
Volume of filtrate + wash	(mL)	1300	1280	1350
Al	(mg/L)	32.8	40.6	47.1
As	(mg/L)	1.0	2.0	0.5
Co	(mg/L)	342	367	366
Fe	(mg/L)	34	71	62
Ni	(mg/L)	3560	3680	3690
Zn	(mg/L)	31	36	37
Wet wt. of precipitate	(g)	361	319.8	311.8
Dry wt. of precipitate	(g)	91.7	90.0	89.3
Al	(%)	2.14	2.33	2.31
As	(%)	5.77	4.97	5.19
Co	(%)	0.06	0.074	0.061
Fe	(%)	9.29	9.67	9.96
Ni	(%)	0.53	0.55	0.51
Zn	(%)	0.018	0.017	0.013

Test No. 26 continued

		Cycle 1	Cycle 2	Cycle 3
Radium Precipitation				
Volume conc. H_2SO_4	(mL)	0.05	0.05	0.05
Volume of 1 g/L $BaCl_2$ $2H_2O$	(mL)	31.5	31.25	32.5
pH		4.0	4.0	4.0
2nd Stage Precipitation				
Volume of 20 g/L Fe^{+3}	(mL)	6.3	6.3	6.5
Wt of 15 % w/w $Ca(OH)_2$	(g)	4.7	4.0	4.1
Fe^{+3} Addition	(mg Fe^{+3}/L)	100	100	100
pH		5.0	5.0	5.0
2nd Stage Filtration				
Volume of filtrate	(mL)	1290	1270	1315
Al	(mg/L)	7.6	10.4	12.7
As	(mg/L)	0.5	0.5	0.5
Co	(mg/L)	324	358	358
Fe	(mg/L)	25	58.9	49.6
Ni	(mg/L)	3450	3650	3650
Zn	(mg/L)	27	33	34
Wet wt. of precipitate	(g)	4.6	3.6	4.3

Test No. 26 continued

			Cycle 1	Cycle 2	Cycle 3
Calculations					
Uranium Raffinate Feed					
Al		(mg)	2100	2100	2100
As		(mg)	5300	5300	5300
Co		(mg)	538	538	538
Fe		(mg)	69	69	69
Ni		(mg)	5400	5400	5400
Zn		(mg)	8	8	8
1st stage Fe+3 addition		(mg)	4200	4200	4200
2nd stage Fe+3 addition		(mg)	126	125	130
1st stage filtrate + wash					
Al		(mg)	42.6	52.0	63.6
As		(mg)	1.3	2.5	0.7
Co		(mg)	444.6	469.8	494.1
Fe		(mg)	44.6	91.0	83.2
Ni		(mg)	4628.0	4710.4	4981.5
Zn		(mg)	40.3	45.8	49.3
1st stage precipitate					
Al		(mg)	1962.4	2097.0	2062.8
As		(mg)	5291.1	4473.0	4634.7
Co		(mg)	55.0	66.6	54.5
Fe		(mg)	8518.9	8703.0	8894.3
Ni		(mg)	486.0	495.0	455.4
Zn		(mg)	16.5	15.3	11.6
1st stage balance					
Al	In/Out x 100	(%)	104.7	97.7	98.8
As	In/Out x 100	(%)	100.1	118.4	114.3
Co	In/Out x 100	(%)	107.7	100.3	98.1
Fe	In/Out x 100	(%)	49.9	48.5	47.6
Ni	In/Out x 100	(%)	105.6	103.7	99.3
Zn	In/Out x 100	(%)	14.1	13.1	13.1
1st stage efficiencies					
Al		(%)	98.0	97.5	97.0
As		(%)	100.0	100.0	100.0
Co		(%)	17.4	12.7	8.2
Fe		(%)	99.0	97.9	98.1
Ni		(%)	14.3	12.8	7.8
Zn		(%)	-403.8	-472.8	-515.9

Test No. 26 continued

		Cycle 1	Cycle 2	Cycle 3
2nd stage filtrate				
Al	(mg)	9.7	13.2	16.7
As	(mg)	0.6	0.6	0.7
Co	(mg)	418.0	454.7	470.8
Fe	(mg)	32.3	74.8	65.2
Ni	(mg)	4450.5	4635.5	4799.8
Zn	(mg)	34.8	42.4	45.0
2nd stage efficiencies				
Al	(%)	77.2	74.6	73.7
As	(%)	50.4	75.1	2.6
Co	(%)	6.0	3.2	4.7
Fe	(%)	81.1	65.4	69.4
Ni	(%)	3.8	1.6	3.6
Zn	(%)	13.6	7.4	8.7
Overall efficiencies				
Al	(%)	99.5	99.4	99.2
As	(%)	100.0	100.0	100.0
Co	(%)	22.3	15.5	12.5
Fe	(%)	99.3	98.3	98.5
Ni	(%)	17.6	14.2	11.1
Zn	(%)	-335.4	-430.2	-462.2

Project No. 4234 **Technician** Warren Reishus
Client: Midwest Joint Ventures **Date:** June 1, 1992

Test No. 26

		Cycle 4	Cycle 5	Cycle 6
Uranium Raffinate Feed				
Volume	(mL)	960	980	980
Wt of 2nd stage precipitate	(g)	4.3	8.0	9.7
Al	(mg/L)	2060	2620	1980
As	(mg/L)	5230	5350	5220
Co	(mg/L)	540	543	528
Fe	(mg/L)	318	264	220
Ni	(mg/L)	5350	5390	5230
Zn	(mg/L)	16.1	19.5	17.8
Oxidation				
Wt of 30 % w/w H2O2	(g)	1.0	1.0	1.0
1st Stage Precipitation				
Volume of 20 g/L Fe+3	(mL)	201.6	205.8	205.8
Wt of 15 % w/w Ca(OH)2	(g)	150.8	154.2	151.1
Fe+3 / As molar ratio		1/1	1/1	1/1
pH		4.5	4.5	4.5
1st Stage Filtration & Washing				
Volume of pH 3.2 H2SO4	(mL)	400	400	400
Volume of filtrate + wash	(mL)	1500	1500	1480
Al	(mg/L)	412	34.1	33.9
As	(mg/L)	162	105	116
Co	(mg/L)	354	330	346
Fe	(mg/L)	59	36	49
Ni	(mg/L)	3470	3320	3460
Zn	(mg/L)	22	19	22
Wet wt. of precipitate	(g)	209.3	274.9	260.4
Dry wt. of precipitate	(g)	58.9	70.4	64.6
Al	(%)	2.4	3.58	3.08
As	(%)	7.39	6.31	6.81
Co	(%)	0.01	0.045	0.03
Fe	(%)	7.75	6.76	7.36
Ni	(%)	0.072	0.34	0.22
Zn	(%)	0.003	0.016	0.036
Ca	(%)	16	16	17
Mg	(%)	0.016	0.017	0.018

Test No. 26 continued

		Cycle 4	Cycle 5	Cycle 6
Radium Precipitation				
Volume conc. H2SO4	(mL)	0.05	0.05	0.05
Volume of 1 g/L BaCl2 2H2O	(mL)	36.9	36.9	36.4
pH		4.0	4.0	4.0
2nd Stage Precipitation				
Volume of 20 g/L Fe+3	(mL)	7.4	7.4	7.3
Wt of 15 % w/w Ca(OH)2	(g)	15.0	4.2	3.4
Fe+3 Addition	(mg Fe+3/L)	100	100	100
pH		5.0	5.0	5.0
2nd Stage Filtration				
Volume of filtrate	(mL)	1510	1495	1480
Al	(mg/L)	13.2	11.8	10.7
As	(mg/L)	81.9	47.9	59.3
Co	(mg/L)	325	300	322
Fe	(mg/L)	39.3	28.9	43.4
Ni	(mg/L)	3270	3050	3250
Zn	(mg/L)	19	16	20
Wet wt. of precipitate	(g)	8.0	9.7	9.5

Test No. 26 continued

Calculations

			Cycle 1	Cycle 2	Cycle 3
Uranium Raffinate Feed					
Al		(mg)	1977.6	2567.6	1940.4
As		(mg)	5020.8	5243	5115.6
Co		(mg)	518.4	532.14	517.44
Fe		(mg)	305.28	258.72	215.6
Ni		(mg)	5136	5282.2	5125.4
Zn		(mg)	15.456	19.11	17.444
1st stage Fe+3 addition		(mg)	4032	4116	4116
2nd stage Fe+3 addition		(mg)	148	148	146
1st stage filtrate + wash					
Al		(mg)	618.0	51.2	50.2
As		(mg)	243.0	157.5	171.7
Co		(mg)	531.0	495.0	512.1
Fe		(mg)	88.4	53.3	72.4
Ni		(mg)	5205.0	4980.0	5120.8
Zn		(mg)	33.3	28.8	32.9
1st stage precipitate					
Al		(mg)	1413.6	2520.3	1989.7
As		(mg)	4352.7	11.3	23.3
Co		(mg)	5.9	31.7	19.4
Fe		(mg)	4564.8	4759.0	4754.6
Ni		(mg)	42.4	239.4	142.1
Zn		(mg)	1.8	#REF!	#REF!
1st stage balance					
Al	In/Out x 100	(%)	97.3	99.8	95.1
As	In/Out x 100	(%)	109.2	3106.7	2624.2
Co	In/Out x 100	(%)	96.6	101.0	97.4
Fe	In/Out x 100	(%)	93.2	90.9	89.7
Ni	In/Out x 100	(%)	97.9	101.2	97.4
Zn	In/Out x 100	(%)	44.1	#REF!	#REF!
1st stage efficiencies					
Al		(%)	68.8	98.0	97.4
As		(%)	95.2	97.0	96.6
Co		(%)	-2.4	7.0	1.0
Fe		(%)	98.0	98.8	98.3
Ni		(%)	-1.3	5.7	0.1
Zn		(%)	-115.5	-50.7	-88.4

Test No. 26 continued

		Cycle 1	Cycle 2	Cycle 3
2nd stage filtrate				
Al	(mg)	19.9	17.6	15.8
As	(mg)	123.7	71.6	87.8
Co	(mg)	490.8	448.5	476.6
Fe	(mg)	59.3	43.2	64.2
Ni	(mg)	4937.7	4559.8	4810.0
Zn	(mg)	27.9	24.2	29.6
2nd stage efficiencies				
Al	(%)	96.8	65.5	68.4
As	(%)	49.1	54.5	48.9
Co	(%)	7.6	9.4	6.9
Fe	(%)	74.9	78.5	70.6
Ni	(%)	5.1	8.4	6.1
Zn	(%)	16.1	15.9	9.9
Overall efficiencies				
Al	(%)	99.0	99.3	99.2
As	(%)	97.5	98.6	98.3
Co	(%)	5.3	15.7	7.9
Fe	(%)	98.7	99.0	98.6
Ni	(%)	3.9	13.7	6.2
Zn	(%)	-80.7	-26.7	-69.7

Project No. 4234 **Technician** Warren Reishus
Client: Midwest Joint Ventures **Date:** May 20, 1992

Test No. 27

		Cycle 1	Cycle 2	Cycle 3
Uranium Raffinate Feed				
Volume	(mL)	1000	1000	1000
Al	(mg/L)	2100	2100	2100
As	(mg/L)	5300	5300	5300
Co	(mg/L)	538	538	538
Fe	(mg/L)	69	69	69
Ni	(mg/L)	5400	5400	5400
Zn	(mg/L)	8.0	8.0	8.0
Oxidation				
Wt of 2nd stage precipitate	(g)	0.0	4.1	3.8
Wt of 30 % w/w H2O2	(g)	2.0	1.9	1.7
1st Stage Precipitation				
Volume of 20 g/L Fe+3	(mL)	210	210	210
Wt of 15 % w/w Ca(OH)2	(g)	206.0	196.7	183.1
Fe+3 / As molar ratio		1/1	1/1	1/1
pH		4.5	4.5	4.5
1st Stage Filtration & Washing				
Volume of pH 3.2 H2SO4	(mL)	150	150	150
Volume of filtrate + wash	(mL)	1170	1130	1200
Al	(mg/L)	39	39.5	41.9
As	(mg/L)	1.0	0.5	0.5
Co	(mg/L)	351	406	385
Fe	(mg/L)	47	70	44
Ni	(mg/L)	3690	4020	3810
Zn	(mg/L)	35	49	48
Wet wt. of precipitate	(g)	327.6	303.8	331.2
Dry wt. of precipitate	(g)	98.4	90.5	94.8
Al	(%)	2.14	2.32	2.25
As	(%)	6.1	4.82	4.83
Co	(%)	0.054	0.062	0.07
Fe	(%)	9.99	9.98	9.46
Ni	(%)	0.49	0.49	0.61
Zn	(%)	0.015	0.017	0.022

Test No. 27 continued

		Cycle 1	Cycle 2	Cycle 3
Radium Precipitation				
Volume conc. H_2SO_4	(mL)	0.05	0.05	0.05
Volume of 1 g/L $BaCl_2\ 2H_2O$	(mL)	32.0	31.3	32.5
pH		4.0	4.0	4.0
2nd Stage Precipitation				
Volume of 20 g/L Fe^{+3}	(mL)	6.4	6.3	6.5
Wt of 15 % w/w $Ca(OH)_2$	(g)	7.1	7.4	7.7
Fe^{+3} Addition	(mg Fe^{+3}/L)	100	100	100
pH		6.0	6.0	6.0
2nd Stage Filtration				
Volume of filtrate	(mL)	1310	1275	1310
Al	(mg/L)	0.8	0.9	1.2
As	(mg/L)	0.5	0.5	0.5
Co	(mg/L)	316	366	354
Fe	(mg/L)	8.84	13	1.25
Ni	(mg/L)	3370	3730	3580
Zn	(mg/L)	18	23	5
Wet wt. of precipitate	(g)	4.1	3.8	3.8

Test No. 27 continued

			Cycle 1	Cycle 2	Cycle 3
Calculations					
Uranium Raffinate Feed					
Al		(mg)	2100	2100	2100
As		(mg)	5300	5300	5300
Co		(mg)	538	538	538
Fe		(mg)	69	69	69
Ni		(mg)	5400	5400	5400
Zn		(mg)	8	8	8
1st stage Fe+3 addition		(mg)	4200	4200	4200
2nd stage Fe+3 addition		(mg)	128	125	130
1st stage filtrate + wash					
Al		(mg)	45.6	44.6	50.3
As		(mg)	1.2	0.6	0.6
Co		(mg)	410.7	458.8	462.0
Fe		(mg)	54.6	79.2	52.4
Ni		(mg)	4317.3	4542.6	4572.0
Zn		(mg)	40.4	55.5	57.6
1st stage precipitate					
Al		(mg)	2105.8	2099.6	2133.0
As		(mg)	6002.4	4362.1	4578.8
Co		(mg)	53.1	56.1	66.4
Fe		(mg)	9830.2	9031.9	8968.1
Ni		(mg)	482.2	443.5	578.3
Zn		(mg)	14.8	15.4	20.9
1st stage balance					
Al	In/Out x 100	(%)	97.6	97.9	96.2
As	In/Out x 100	(%)	88.3	121.5	115.7
Co	In/Out x 100	(%)	116.0	104.5	101.8
Fe	In/Out x 100	(%)	43.2	46.9	47.3
Ni	In/Out x 100	(%)	112.5	108.3	104.8
Zn	In/Out x 100	(%)	14.5	11.3	10.2
1st stage efficiencies					
Al		(%)	97.8	97.9	97.6
As		(%)	100.0	100.0	100.0
Co		(%)	23.7	14.7	14.1
Fe		(%)	98.7	98.1	98.8
Ni		(%)	20.1	15.9	15.3
Zn		(%)	-404.6	-593.5	-620.0

Test No. 27 continued

		Cycle 1	Cycle 2	Cycle 3
2nd stage filtrate				
Al	(mg)	1.0	1.2	1.6
As	(mg)	0.7	0.6	0.7
Co	(mg)	414.0	466.7	463.7
Fe	(mg)	11.6	16.6	1.6
Ni	(mg)	4414.7	4755.8	4689.8
Zn	(mg)	23.1	29.7	7.0
2nd stage efficiencies				
Al	(%)	97.7	97.3	96.8
As	(%)	44.0	-12.8	-9.2
Co	(%)	-0.8	-1.7	-0.4
Fe	(%)	93.7	91.9	99.1
Ni	(%)	-2.3	-4.7	-2.6
Zn	(%)	42.9	46.5	87.8
Overall efficiencies				
Al	(%)	100.0	99.9	99.9
As	(%)	100.0	100.0	100.0
Co	(%)	23.1	13.3	13.8
Fe	(%)	99.7	99.6	100.0
Ni	(%)	18.2	11.9	13.2
Zn	(%)	-188.2	-271.3	12.4

Project No. 4234
Client: Midwest Joint Ventures

Technician Warren Reishus
Date: June 1, 1992

Test No. 27

		Cycle 4	Cycle 5	Cycle 6
Uranium Raffinate Feed				
Volume	(mL)	970	980	980
Wt of 2nd stage precipitate	(g)	3.8	8.7	9.9
Al	(mg/L)	2080	2550	2030
As	(mg/L)	5250	5000	5250
Co	(mg/L)	571	570	575
Fe	(mg/L)	365	327	269
Ni	(mg/L)	5550	5530	5580
Zn	(mg/L)	37.7	56.6	50.6
Oxidation				
Wt of 30 % w/w H_2O_2	(g)	1.0	1.0	1.0
1st Stage Precipitation				
Volume of 20 g/L Fe^{+3}	(mL)	203.7	205.8	205.8
Wt of 15 % w/w $Ca(OH)_2$	(g)	150.0	147.7	148.0
Fe^{+3} / As molar ratio		1/1	1/1	1/1
pH		4.5	4.5	4.5
1st Stage Filtration & Washing				
Volume of pH 3.2 H_2SO_4	(mL)	400	400	400
Volume of filtrate + wash	(mL)	1495	1490	1495
Al	(mg/L)	418	27.9	24.3
As	(mg/L)	40	90	113
Co	(mg/L)	345	368	363
Fe	(mg/L)	82	47	49
Ni	(mg/L)	3340	3600	3530
Zn	(mg/L)	44	41	39
Wet wt. of precipitate	(g)	218.6	266.6	252.3
Dry wt. of precipitate	(g)	99.3	70.3	66.6
Al	(%)	2.06	3.69	3.1
As	(%)	6.41	6.24	6.88
Co	(%)	0.01	0.043	0.036
Fe	(%)	9.82	6.95	7.59
Ni	(%)	0.089	0.33	0.25
Zn	(%)	0.004	0.024	0.012
Ca	(%)	15	16	17
Mg	(%)	0.019	0.023	0.027

Test No. 27 continued

		Cycle 4	Cycle 5	Cycle 6
Radium Precipitation				
Volume conc. H2SO4	(mL)	0.05	0.05	0.05
Volume of 1 g/L BaCl2 2H2O	(mL)	36.75	36.6	36.75
pH		4.0	4.0	4.0
2nd Stage Precipitation				
Volume of 20 g/L Fe+3	(mL)	7.4	7.3	7.4
Wt of 15 % w/w Ca(OH)2	(g)	21.2	6.2	4.6
Fe+3 Addition	(mg Fe+3/L)	100	100	100
pH		6.0	6.0	6.0
2nd Stage Filtration				
Volume of filtrate	(mL)	1480	1485	1485
Al	(mg/L)	2.8	0.8	1.6
As	(mg/L)	7.5	18.7	35.6
Co	(mg/L)	313	308	333
Fe	(mg/L)	12.5	9.04	29
Ni	(mg/L)	3170	3120	3300
Zn	(mg/L)	12	12	27
Wet wt. of precipitate	(g)	8.7	9.9	10.0

Test No. 27 continued

Calculations			Cycle 4	Cycle 5	Cycle 6
Uranium Raffinate Feed					
Al		(mg)	2017.6	2499	1989.4
As		(mg)	5092.5	4900	5145
Co		(mg)	553.87	558.6	563.5
Fe		(mg)	354.05	320.46	263.62
Ni		(mg)	5383.5	5419.4	5468.4
Zn		(mg)	36.569	55.468	49.588
1st stage Fe+3 addition		(mg)	4074	4116	4116
2nd stage Fe+3 addition		(mg)	147	146	147
1st stage filtrate + wash					
Al		(mg)	624.9	41.6	36.3
As		(mg)	60.2	133.4	168.9
Co		(mg)	515.8	548.3	542.7
Fe		(mg)	122.9	69.4	73.3
Ni		(mg)	4993.3	5364.0	5277.4
Zn		(mg)	65.2	60.9	57.7
1st stage precipitate					
Al		(mg)	2045.6	2594.1	2064.6
As		(mg)	6365.1	4386.7	4582.1
Co		(mg)	9.9	30.2	24.0
Fe		(mg)	9751.3	4885.9	5054.9
Ni		(mg)	88.4	232.0	166.5
Zn		(mg)	4.0	16.9	8.0
1st stage balance					
Al	In/Out x 100	(%)	75.6	94.8	94.7
As	In/Out x 100	(%)	79.3	108.4	108.3
Co	In/Out x 100	(%)	105.4	96.8	99.4
Fe	In/Out x 100	(%)	44.8	89.5	85.4
Ni	In/Out x 100	(%)	105.9	96.8	100.5
Zn	In/Out x 100	(%)	52.9	71.3	75.5
1st stage efficiencies					
Al		(%)	69.0	98.3	98.2
As		(%)	98.8	97.3	96.7
Co		(%)	6.9	1.8	3.7
Fe		(%)	97.2	98.4	98.3
Ni		(%)	7.2	1.0	3.5
Zn		(%)	-78.2	-9.9	-16.4

Test No. 27 continued

		Cycle 4	Cycle 5	Cycle 6
2nd stage filtrate				
Al	(mg)	4.1	1.1	2.4
As	(mg)	11.0	27.8	52.9
Co	(mg)	463.2	457.4	494.5
Fe	(mg)	18.5	13.4	43.1
Ni	(mg)	4691.6	4633.2	4900.5
Zn	(mg)	17.0	17.7	40.1
2nd stage efficiencies				
Al	(%)	99.3	97.3	93.4
As	(%)	81.7	79.2	68.7
Co	(%)	10.2	16.6	8.9
Fe	(%)	93.1	93.8	80.4
Ni	(%)	6.0	13.6	7.1
Zn	(%)	73.9	71.0	30.5
Overall efficiencies				
Al	(%)	99.8	100.0	99.9
As	(%)	99.8	99.4	99.0
Co	(%)	16.4	18.1	12.2
Fe	(%)	99.6	99.7	99.0
Ni	(%)	12.9	14.5	10.4
Zn	(%)	53.5	68.1	19.1

Project No.	LR 4234
Client:	Midwest Joint Ventures
Project Techician:	Warren Reishus
Date:	June 8, 1992

Test No. 26 Continued

Objective: To conduct a Co-Ni precipitation test on the purified raffinate solution using Na_2CO_3 at 50°C.

Procedure:

1 Transfer 1420 mL of raffinate to a 2 L reaction vessel. Include agitator, impeller, and baffle.
2 Slowly add 93 mL of 200 g/L Na_2CO_3 solution to pH 8.67.
3 Let react at 50 °C for 30 min.
4 Filter the sample through 0.6 μm paper and submit the filtrate for Al, As, Co, Fe, Ni and Zn.
5 Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Purified raffinate solution (from Test No. 26 Cycle No. 6)

Conditions:

Na_2CO_3 addition	Neutralized to pH 8.65	
Temperature	50	°C
Reaction Time	0.5	h
pH	8.67	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	1330 mL	0.1	1.8	0.74	0.02	8.8	0.01	0.7	2.9	0.2	0.1	0.3	0.0
Precipitate	14.5 g	0.13	0.55	3.04	0.36	31.2	0.19	99.3	97.1	99.8	99.9	99.7	100.0
Feed (calc.)	1420 mL	13.4	57.8	311	36.8	3194	19.4	100	100	100	100	100	100
Feed (assay)		10.7	59.3	322	43.4	3250	20.0						

Product	Amount	Analyses (mg/L, %)					Bq/g	Distribution (%)					
		Ca	Mg	U			Ra	Ca	Mg	U			
Barren Sol'n	1330 mL	24.9	220	1				3.8	50.5	97.9			
Precipitate	14.5 g	5.7	2.0	0.0002			0.02	96.2	49.5	2.1			
Feed (calc.)	1420 mL	609	408	1				100	100	100			
Feed (assay)													

Comments: Filtercake wet wt. 85.45 g

Project No. LR 4234
Client: Midwest Joint Ventures
Project Techician: Warren Reishus
Date: June 8, 1992

Test No. 27 Continued

Objective: To conduct a Co-Ni precipitation test on the purified raffinate solution using Na2CO3 at 50°C.

Procedure:
1 Transfer 1390 mL of raffinate to a 2 L reaction vessel. Include agitator, impeller, and baffle.
2 Slowly add 90 mL of 200 g/L Na2CO3 solution to pH 8.67.
3 Let react at 50 °C for 30 min.
4 Filter the sample through 0.6 µm paper and submit the filtrate for Al, As, Co, Fe, Ni and Zn.
5 Record the wet and dry weights of the precipitate and submit for analyses.

Feed: Purified raffinate solution (from Test No. 27 Cycle No. 6)

Conditions:

Na2CO3 addition	Neutralized to pH 8.66	
Temperature	50	°C
Reaction Time	0.5	h
pH	8.66	

Data:

Product	Amount	Analyses (mg/L, %)						Distribution (%)					
		Al	As	Co	Fe	Ni	Zn	Al	As	Co	Fe	Ni	Zn
Barren Sol'n	1245 mL	0.1	2.4	0.90	0.02	228.0	10.10	0.9	6.7	0.3	0.1	6.4	26.5
Precipitate	13.4 g	0.10	0.31	3.08	0.21	30.9	0.26	99.1	93.3	99.7	99.9	93.6	73.5
Feed (calc.)	1390 mL	9.7	32.0	298	20.3	3183	34.1	100	100	100	100	100	100
Feed (assay)		1.6	35.6	333	29.0	3300	27.0						

Product	Amount	Analyses (mg/L, %)					Bq/g	Distribution (%)					
		Ca	Mg	U			Ra	Ca	Mg	U			
Barren Sol'n	1245 mL	29.7	228	1				4.2	52.3	99.1			
Precipitate	13.4 g	6.2	1.9	0.0001			0.02	95.8	47.7	0.9			
Feed (calc.)	1390 mL	628	390					100	100	100			
Feed (assay)													

Comments: Filtercake wet wt. 91.9 g

Volume

2

NICKEL/COBALT RECOVERY
FROM
MIDWEST RAFFINATE SOLUTION
- PROJECT FINAL REPORT -
VOLUME II

MIDWEST JOINT VENTURE
Contract No. 23440-1-9153/01-SQ

128 pp

MICROMEDIA

Appendix B

EIMCO

Thickening and Filtration

Testwork Report

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

601 45th Street West
Saskatoon, Saskatchewan
S7L 5W5

MIDWEST JOINT VENTURE

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

THICKENING AND FILTRATION REPORT

Covering

Ist-Stage Pre-Treatment Thickening & Filtration

2nd-Stage Pre-Treatment Clarification

Ni/Co Precipitate Clarification and Filtration

For

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

By

W. W. Stone, P.ENG.

EIMCO PROCESS EQUIPMENT

P.0. Box 54, Washago, Ontario
L0K 2B0

August 24, 1992

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SECTION 1.0

INTRODUCTION and OBJECTIVES

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

SECTION 1.0 - INTRODUCTION & OBJECTIVES

INTRODUCTION

EIMCO Process Equipment was requested by Denison Mines Limited, Saskatoon, to conduct thickening and filtration test work on a variety of liquid-solid separation applications in the Ni/Co recovery from Midwest raffinate solution process. The test samples were prepared by Lakefield Research. This test work was conducted during the period July 6-9 and July 18, 1992 by Mr. W.W. Stone, EIMCO Process Equipment, Washago, Ontario, at Lakefield Research.

OBJECTIVES

A) 1st-Stage Pre-Treatment Precipitate Thickening

The objective of this investigation was to:

- *conduct bench-scale thickening tests on a representative sample of a 1st-Stage precipitate slurry.*
- *determine the design unit area and rise rate for thickener sizing based upon the following variables;*
  - *Flocculant addition.*
  - *Feed Solids Concentration.*
  - *Underflow Solids Concentration.*

B) 1st-Stage Pre-Treatment Precipitate Vacuum Filtration

The objective of this investigation was to:

- *conduct bench-scale vacuum filtration tests on a representative sample of 1st-Stage Precipitate slurry.*

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

SECTION 1.0 - INTRODUCTION & OBJECTIVES

INTRODUCTION

B) 1st-Stage Pre-Treatment Precipitate Vacuum Filtration

- *determine the full-scale filtration rate for an EIMCO-Extractor, horizontal belt filter based upon the following variables;*
  - *Feed Solids Concentration.*
  - *Vacuum Levels.*
  - *Filter Cake Thickness.*
  - *Filter Cake Moisture.*
  - *Soluble Ni Cake Wash Efficiency.*

C) 2nd-Stage Pre-Treatment Precipitate Thickening and Clarification

The objective of this investigation was to:

- *conduct bench-scale thickening and clarification tests on a fresh representative sample of 2nd-Stage precipitate slurry.*
- *determine the EIMCO Reactor-Clarifier design unit area and rise rate under various operating variables for this clarifier application:*
  - *Flocculant addition.*
  - *Flocculant Dosage.*
  - *Feed Solids Concentration*
  - *Underflow Solids Concentration*

SECTION 1.0 - INTRODUCTION & OBJECTIVES

INTRODUCTION

D) Ni/Co Precipitate Thickening/Clarification

The objective of this investigation was to:

- *conduct bench-scale thickening tests on a fresh representative sample of Ni/Co precipitate slurry.*
- *determine the thickener design unit area and clarifier rise rate under various operating variables for this thickening/clarifier application:*
    - ■ *Flocculant addition.*
    - ■ *Flocculant Dosage.*
    - ■ *Underflow Solids Concentration*

E) Ni/Co Precipitate Pressure Filtration

The objective of this investigation was to:

- *conduct bench-scale pressure filtration tests on a fresh representative sample of Ni/Co precipitate slurry.*
- *determine the filtration rate and other pressure filter operating requirements and design features.*

SECTION 2.0

SUMMARY

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

SECTION 2.0 - SUMMARY

A) 1st-Stage Pre-Treatment Precipitate Thickening

A total of three (3) EIMCO conventional bench-scale thickening tests were conducted on the sample of 1st-Stage Iron/Gypsum Precipitate slurry. From this work we recommend that consideration be given to the following:

Feed Solids Concentration (wt%)	*Polymer Type/Dose (g/tonne)*	*Final Solids Conc. (wt%)*	*Design Unit Area (m^2/t/d) @ u/f density*
2-4	*Percol E-10* *30-40*	*15-20*	*2*

1) *The iron/gypsum precipitate produced in this 1st-Stage reaction formed a large fluffy precipitate that had a slow thickening rate to reach the higher underflow solids concentration. At a design unit area of 2.0 m^2/t/d we can expect to achieve an underflow solids concentration in the 15-20 wt% solids range.*

2) *Based upon a thickener feed rate of 2.63 mtph and a design unit area of 2.0 m^2/t/d a 12802 mm diameter thickener is required. The back calculated rise rate for this size thickener at a feed rate of 67.4 m^3/h is 0.52 m^3/m^2/h.*

3) *A flocculant addition of approximately 40 g/tonne dry precipitate is required to achieve this thickening rate and to reduce the suspended solids in the thickener overflow. Allied Colloid's Percol E-10 was used in this application.*

4) *The slurry received was at a density of 8 weight percent. A number of beaker tests were run to establish an acceptable feed solids concentration to achieve good flocculation and settling rates. A feed density of 2-4 weight percent is a good design range for this thickener.*

SECTION 2.0 - SUMMARY

A) 1st-Stage Pre-Treatment Precipitate Thickening

5) In the thickening tests the final underflow solids concentration was in the 15-20 weight percent solids range. Therefore a thickened underflow solids concentration in the operating thickener can be expected to be at approximately 20 wt%. Since the thickened slurry will be filtered the higher underflow density is preferred although the underflow pumping requirements should be based on a design density of 15 weight percent.

6) In this test work the flocculant and slurry were mixed very well so consideration should be given to a mixing type feed well.

B) 1st-Stage Pre-Treatment Precipitate Filtration

A total of sixteen (16) EIMCO standard top feed bench-scale filtration tests were conducted on the 1st-Stage Precipitate slurry sample. From this work we recommend that consideration be given to the following filter design specifications:

Filter Design Summary

Full-Scale Filtration Rate, (kg/m^2.h)	*84*
Feed Solids Concentration, (wt%)	*15-20*
Final Cake Moisture, (wt%)	*65*
Filter Cake Thickness, (mm)	*15*
Filter Media Type	*POPR*
Average Vacuum Air Rate, (m^3/h/m^2)	*143.7*
Vacuum , (mm Hg)	*508*

SECTION 2.0 - SUMMARY

B) 1st-Stage Pre-Treatment Precipitate Filtration

Filter Design Summary

Wash Water Requirement, (kg wash/kg dry solids)	*4.64*
Filter Configuration Recommended	*EIMCO-Extractor* *Top Feed* *Horizontal Belt Filter*

1) *A top feed filter was tested exclusively for this iron/Gypsum precipitate dewatering application. Filter cake washing will be required on this filter to remove the soluble nickel and cobalt from the iron/Gypsum filter cake.*

2) *The feed solids concentration was at approximately 15 weight percent solids. We would expect that the 1st-Stage thickener will produce an underflow of around 20 weight percent and this will be satisfactory as filter feed solids concentration. A lower feed solids concentration will increase the form time and overall filter cycle time.*

3) *Most of the test work was conducted at a form vacuum level of 508 mm of Hg. The iron/gypsum filter cake cracked during the drying portion of the filter cycle and the vacuum dropped off to 356-406 mm Hg. The filter will have to be operated to reduce loss of vacuum due to filter cake cracking.*

4) *Filter cake washing tests were conducted on this iron/gypsum filter cake to wash out the soluble nickel and cobalt. We calculate that the soluble nickel concentration in the filter cake can be reduced by approximately 99.6% at a wash ratio of 2.5. A material balance for this wash filter is attached for your reference. A filter cake wash water requirement at the 2.5 wash ratio is 4.64 kgs wash/kg of dry solids.*

SECTION 2.0 - SUMMARY

B) 1st-Stage Pre-Treatment Precipitate Filtration

5) *The final cake moisture of approximately 65 weight percent is limited due to cake cracking and of course the material characteristics.*

6) *Based upon a feed rate of 2.63 mtph we calculate that an EIMCO-Extractor, model 3M30, horizontal belt filter, having 30m^2 of effective filtration area is required.*

C) 2nd-Stage Pre-Treatment Precipitate Thickening and Clarification

One (1) EIMCO conventional bench-scale thickening test and four (4) standard clarification tests were conducted on the sample of 2nd-Stage precipitate slurry. From this work we recommend that consideration be given to the following:

Feed Solids Conc. (wt%)	*Polymer Type/Dosage (mg/L)*	*Final Solids Concentration (wt%)*	*Design Rise Rate (L/min/m^2)*	*Design Unit Area (m^2/t/d)*
1-2	*Percol E-10 0.5-1.0*	*5-10*	*32*	*2-3*

1) *The sizing design constraints for this application is based upon typical clarifier sizing requirements. We conducted one standard thickening test and four clarification tests to determine the clarifier rise rate to achieve an acceptable overflow suspended solids concentration. Attached to this report is the data from that work.*

2) *A design rise rate of about 32 L/min/m^2 was selected to produce a thickener overflow solids loading of 50-70 ppm. And the clarifier is sized based upon this hydraulic loading. At a feed rate of 52 m^3/hr a 6096 mm diameter clarifier is required.*

SECTION 2.0 - SUMMARY

C) 2nd-Stage Pre-Treatment Precipitate Thickening and Clarification

3) *Allied Colloid's Percol E-10 was used in this test work. A dosage of around 0.5 -1.0 mg/L is recommended and the dosage requirement will be controlled depending upon thickener overflow clarity and feed density.*

4) *In the thickening test the final underflow solids reached 8.6 wt% solids. Therefore, we can expect thickened solids in the 10 to 15 weight percent range on constant basis. A 5 wt% solids underflow can be used for pumping design.*

5) *The thickening and clarification tests were run at 0.5-2.0 wt% feed solids concentration. At this low feed solids concentration we recommend that consideration be given to the application of an EIMCO Reactor-Clarifier.*

SECTION 2.0 - SUMMARY

D) Ni/Co Precipitate Thickening/Clarification

Three (3) EIMCO conventional bench-scale thickening tests and two clarification tests were conducted on the sample of nickel/cobalt slurry. From this work we recommend that consideration be given to the following:

Feed Solid Conc. (wt%)	*Polymer Type/Dose (mg/L)*	*Final Solid Conc. (wt%)*	*Design Unit Rise Rate (L/min/m^2)*
0.1-0.5	*Percol E-10* 0.5-1.0	10	7

SECTION 2.0 - SUMMARY

D) Ni/Co Precipitate Thickening and Clarification

1) An EIMCO Reactor-Clarifier should be considered for this nickel/cobalt precipitate. The low feed solids concentrations necessitate internal sludge recirculation to achieve acceptable flocculation, maximizing the rise rate, and minimize the overflow suspended solids.

2) The nickel/cobalt clarifier is sized based upon a rise rate of 7 $l/min/m^2$. At a feed rate of 55.0 m^3/hr a 12802 mm diameter Reactor-Clarifier is required. At this sizing we would expect the clarity of the overflow to be 50-100 ppm suspended solids.

3) The sample was tested as received at an initial solids concentration of 1.0 wt% solids. In actual fact the full scale clarifier will be operating at a feed density of 0.1-0.5 wt%.

4) From the results flocculant is required at a dosage of approximately 1 g/m^3 of feed. Allied Colloid's Percol E-10 was used on this testing.

4) All of the thickening tests produced a final thickened solids concentration of about 7 wt% solids. Through retention time and increased pulp depth the actual underflow solids concentration will likely increase to around 15 wt% solids. The thickened Ni/Co sludge produced for the pressure filtration tests thickened to 15 wt% solids. Other work that EIMCO has done on a nickel carbonate precipitate also indicates that the clarifier solids will thicken to at least 15 wt% solids.

SECTION 2.0 - SUMMARY

E) Ni/Co PRECIPITATE PRESSURE FILTRATION

Two (2) EIMCO standard bench-scale pressure filtration tests were conducted on the Ni/Co Precipitate slurry sample. From this work we recommend that consideration be given to the following filter design specifications:

Filter Design Summary

Feed Solids Concentration, (wt%)	*15*	
Dry Cake Density, (kg\m^3)	*974*	*(60.8 lbs/ft^3)*
Filter Cake Solids, (wt%)	*57*	
Feed Rate (approximate), (L/min/m^2)	*0.48*	
Full Scale Cycle Time, mins.	*80*	
Cake Thickness, (mm)	*31.8*	
Solids Feed Rate, (kg/h)	*278*	
Maximum Design Pressure, (kPa)	*690*	

1) *Based upon a dry solids feed rate of 278 kg/h and the filtration rates achieved in the bench-scale testing we recommend that consideration be given to the application of one (1) Shriver, model 1200, filter press having 33 recessed chambers. This press is sized for a cycle time of approximately 4.5 hours. The extended cycle time reduces the number of dump cycles and operator attention.*

2) *The test work was conducted at a feed solid of approximately 16 weight percent.The Ni/Co precipitate was allowed to thicken over night and was tested at that density.*

SECTION 2.0 - SUMMARY

E) Ni/Co PRECIPITATE PRESSURE FILTRATION

3) The slurry was tested at approximately 20°C. In actual practice the slurry will be hot at about 50°C. The increase in the slurry feed temperature will be beneficial to the filter performance.

4) A wet cake sample was prepared to represent the consistency and handling stability of this filter cake product. This sample was given to Lakefield Research.

5) The filter media used in this testing, that was found to optimize the filtration rate and reduce the suspended solids in the pressate, was a polypropylene 336 HS.

6) The formed filter cake had an air blow for a period of 5 minutes to increase the solids concentration. The filter design will require approximately 18.3 $m^3/h/m^2$, (1 cfm/ft^2), of plant air for filter cake drying.

SECTION 3.0

1st-STAGE PRE-TREATMENT PRECIPITATE THICKENING

DISCUSSION AND CONCLUSIONS

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

SECTION 3.0 - DISCUSSION & CONCLUSIONS

A) 1st-Stage Pre-Treatment Precipitate Thickening

For this 1st-Stage Iron/Gypsum Precipitate thickener application we ran conventional thickening tests on a sample as received from the Lakefield. This thickener receives a slurry feed from the first stage treatment two-stage pachuca in which ferric sulphate and lime are added. The ph is adjusted to 4.5 to precipitate iron and gypsum for thickening and filtration.

Four (4) conventional bench-scale thickening tests were conducted on the sample of iron/gypsum precipitate slurry. The thickening tests were conducted in a two litre glass cylinder outfitted with a slow turning picket rake mechanism. The slurry was thoroughly mixed and flocculant added and the picket rakes inserted. The interface height was observed and recorded versus time. The slurry was allowed to settle for 3-4 hours. The data from the test work was correlated to determine the design unit area for thickener sizing. Attached is the result of the thickening test work along with the graphic illustration of the settling and thickening rates.

From the results of this testing we sized the thickener based upon the design unit area required to achieve an underflow solids concentration of 15-20 weight percent solids.

Flocculant Type and Dosage

In this thickening test work Allied Colloid's Percol E-10 was used. We did not conduct a detailed flocculant scoping study however, beaker tests were conducted for non-ionic, anionic, and cationic polymers. In this testing Percol E-10 an anionic polymer was selected. Other flocculants could also apply and plant trials would identify the most economical flocculant for this application. In three of the thickening tests we increased the flocculant dosage from 17 to 57 gms/tds. While the increase in flocculant dosage increased the settling rate we seen little effect on the thickening rate. Therefore the flocculant dosage is required to tie up the fines and maintain a reasonable rise rate or settling rate in the thickener. A flocculant dosage of approximately 30-40 g/tonnes of dry solids will be required.

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

SECTION 3.0 - DISCUSSION & CONCLUSIONS

A) 1st-Stage Pre-Treatment Thickening

Slurry Flocculant Mixing Intensity

Adding flocculant to the feed slurry and the appropriate mixing of this slurry is of course important to obtain effective flocculation. In this testing we applied a fairly rigorous flocculant/slurry mix intensity. Consideration should be given to a mixing type feed well or some type of external mixer. We were asked to consider a high capacity thickener for this application on the outset of the test work. It would be sufficient to install an EIMCO 'E-Duc' and deep feed well. We could also consider a square feed well to promote the mixing.

Thickener Underflow Solids Concentration

From the thickening tests the final solids concentration was in the 15 weight percent range. This density is adequate for the filtration test work that was conducted. I would expect that we would easily realize a final ultimate density of 20 weight percent. The higher thickener density will only improve the filter form rate and will not be detrimental to the filter performance.

Thickener Design Unit Area

The thickener sizing is calculated based upon a design unit area of 2 m^2/t/d and a thickener feed rate of 2.36 tonnes per day. Test No. 3E was conducted at a slightly higher feed solids concentration and this extra volume of sludge in the cylinder resulted in a lower design unit area requirement for the design underflow solids concentration of 15 weight percent solids. The selection of 2.0 m^2/t/d as the design unit area is a good number to ensure that we continuously produce a sludge density of 15% plus.

SECTION 3.0 - DISCUSSION & CONCLUSIONS

A) 1st-Stage Pre-Treatment Thickening

Feed Solids Concentration

The slurry was tested at a feed solids concentration of approximately 1.5 wt%. Based upon some preliminary beaker tests the slurry will effectively flocculate at a solids concentration of 2-4 weight percent. The flow sheet calls for a feed solids concentration of 4.7 weight percent. It may be necessary to apply some dilution to the slurry feed. An EIMCO E-Duc system may be considered.

MIDEWEST JOINT VENTURE

(DENISON MINES LIMITED – OPERATOR)

1st-STAGE PRE-TREATMENT PRECIPITATE THICKENING SUMMARY

Test NO.	Feed Solids Conc. (wt%)	Polymer Dosage (g/tonnes)	Final Solids Conc. (wt%)	Design Unit Area $m^2/t/d$ @ u/f density 10 wt%	13 wt%	Test Conditions
1E	1.4	17.6	13.8	1.8	2.4	Floc Percol E-10
4E	1.5	34.0	14.9	1.1	2.8	Floc Percol E-10 Increased
5A	1.3	57.9	13.9	1.0	2.4	Floc Dosage E-10 Increased
3E	3.0	32.8	14.4	1.5	1.5	Increased Feed Solids

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                        EIMCO PROCESS EQUIPMENT COMPANY
                          THICKENER TEST SUMMARY SHEET

TEST ID: MINATCO/MIDWEST                                     CREATED: Aug 18, 1997
         HI-CAP TEST #19                                     UPDATED: Aug 18, 1997

STORAGE FILE: /ROBISON/WORK/MINATCO/MIDWEST19.THK                TIME (MIN)   HEIGHT (ML)
                                                                     0.00        2000.
FLOCCULANT: E-10                    CONCENTRATION (G/L):   1.00       .50        1960.
                                    VOLUME ADDED (ML):      .4       1.00        1870.
                                    DOSAGE:               17.6  G/MT 2.00        1660.
                                                                     3.00        1470.
SETTLING VESSEL SIZE (ML/FT):   1669.                                5.00        1150.
UNDECANTED SLURRY VOLUME (ML):  1940.7                               7.00         950.
           SLURRY WEIGHT (G):   2997.60    TARE (G):  997.60         9.00         870.
DECANTED SLURRY VOLUME (ML):     199.9                              11.00         760.
           SLURRY WEIGHT (G):   1008.00                             14.00         660.
DRY SOLIDS WEIGHT (G):           296.60    TARE (G):  290.00        16.00         580.
ULTIMATE INTERFACE HEIGHT (ML):  189.                               20.00         510.
                                                                    25.00         470.
SPECIFIC GRAVITY SUPERNATANT       1.0000                           32.00         410.
SPECIFIC GRAVITY SOLIDS            2.6994                           37.00         360.
                                                                    47.00         290.
                                                                    61.00         260.
UNDERFLOW CONCENTRATION      WEIGHT % SOLIDS        CU (MT/CU.M)    96.00         225.
    INITIAL                        1.47               .01543       141.00         205.
    MINIMUM DESIRED                9.63               .10791       201.00         195.
    FINAL (TEST)                  13.33               .14829      ********     ********
    ULTIMATE                      13.76               .16177      ********     ********
                                                                  ********     ********
                                                                  ********     ********
    UNDERFLOW            UNDERFLOW           UNIT AREA         UNIT AREA        ********     ********
 WEIGHT % SOLIDS       CU (MT/CU.M)        SQ.M/MTPD      SQ.M/MTPD CORRECTED   ********     ********
                                                                  ********     ********
      13.3               .15875             21.711            2.756         ********     ********
      13.0               .15270             17.367            2.339         ********     ********
      12.0               .13964             10.546            1.717         ********     ********
      11.0               .12719              7.177            2.000         ********     ********
      10.0               .11489              6.014            1.760         ********     ********
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Figure __ BATCH INTERFACE SETTLING DATA
MINATCO/MIDWEST
MI-CAP TEST #19

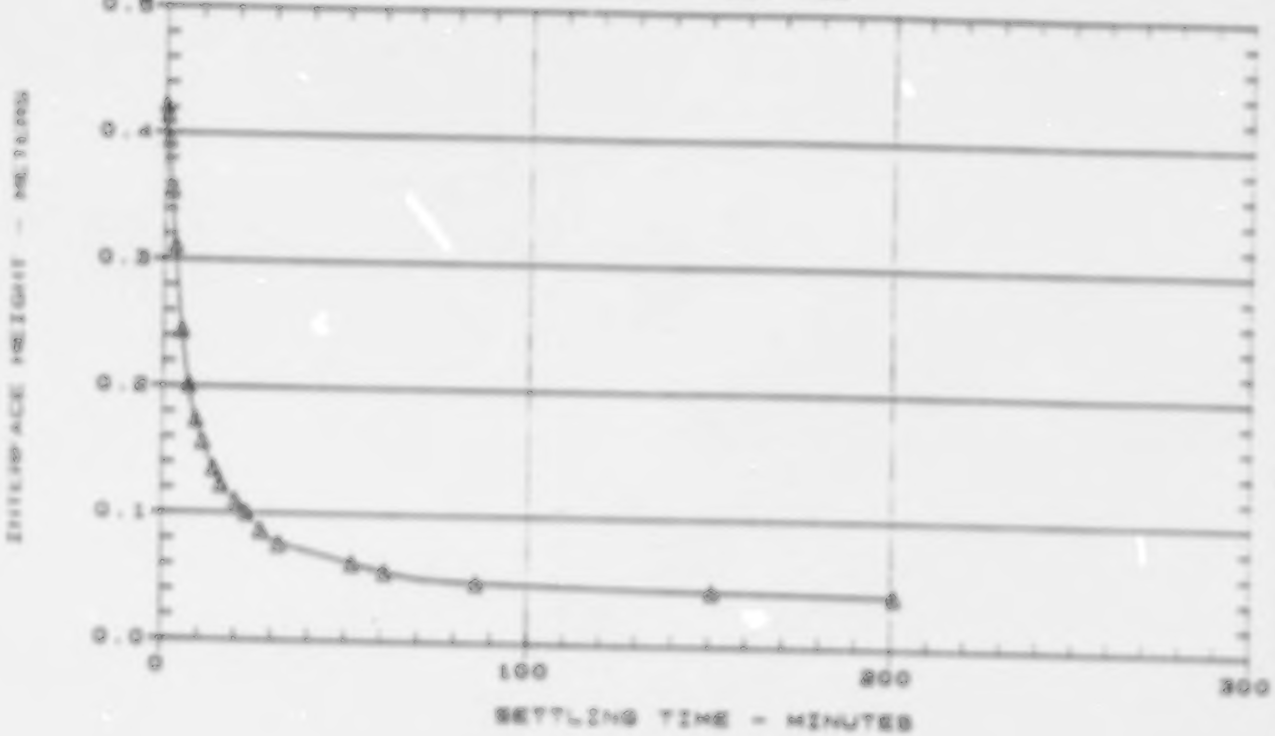
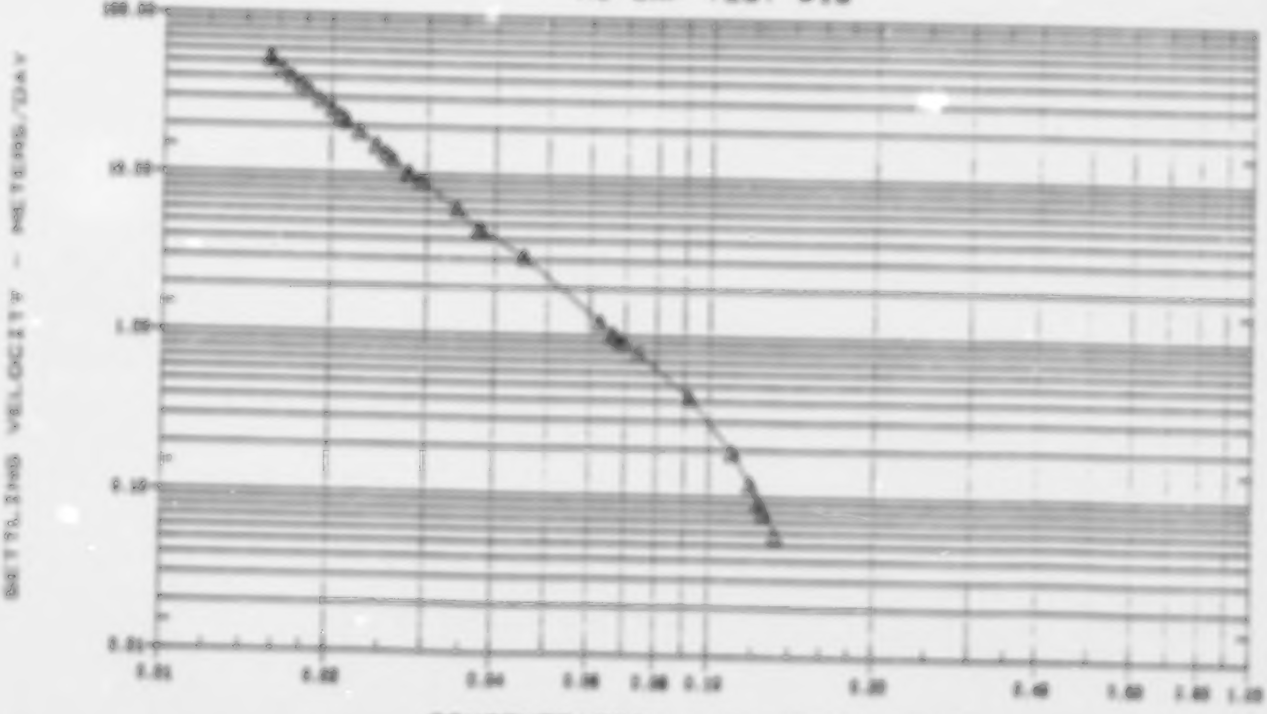


Figure __ SETTLING VEL vs CONCENTRATION
MINATCO/MIDWEST
MI-CAP TEST #19



AUG 10, 1992 MINATCO/MIDWEST19

Figure __ UNIT AREA vs UF CONCENTRATION
MINATCO/MIDWEST
MI-CAP TEST #19

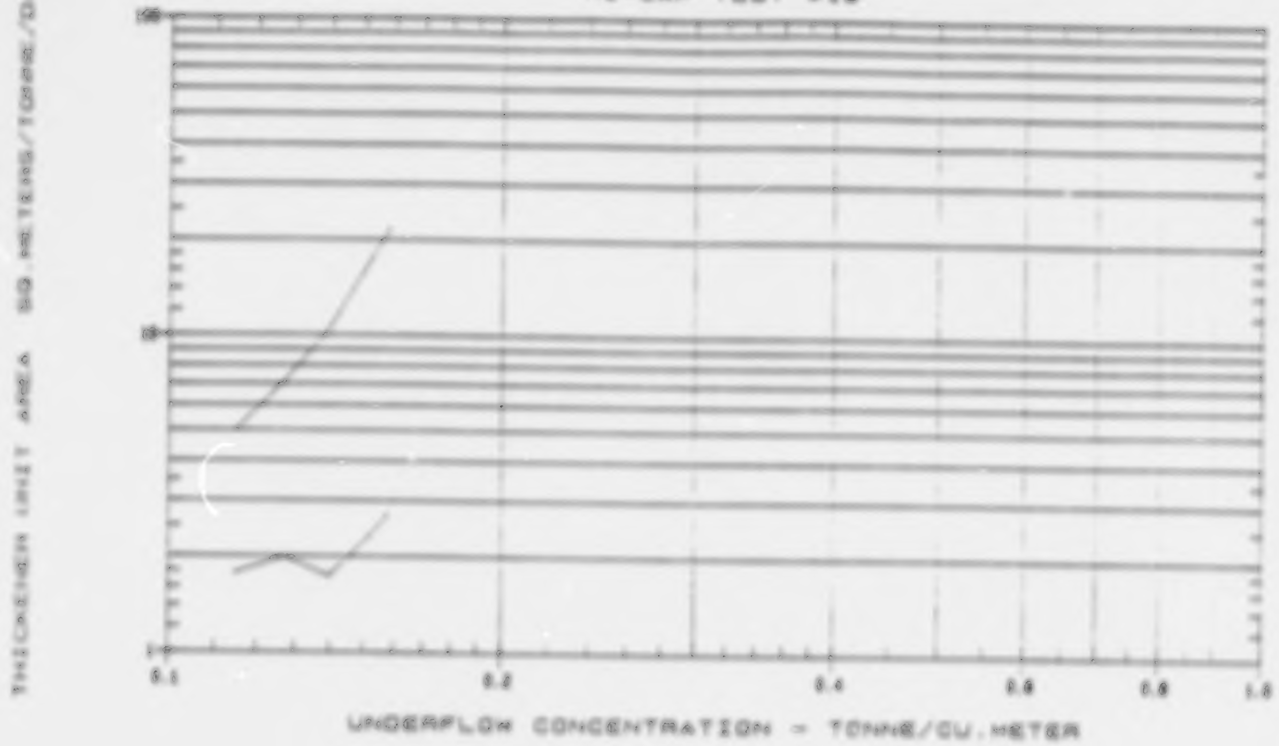
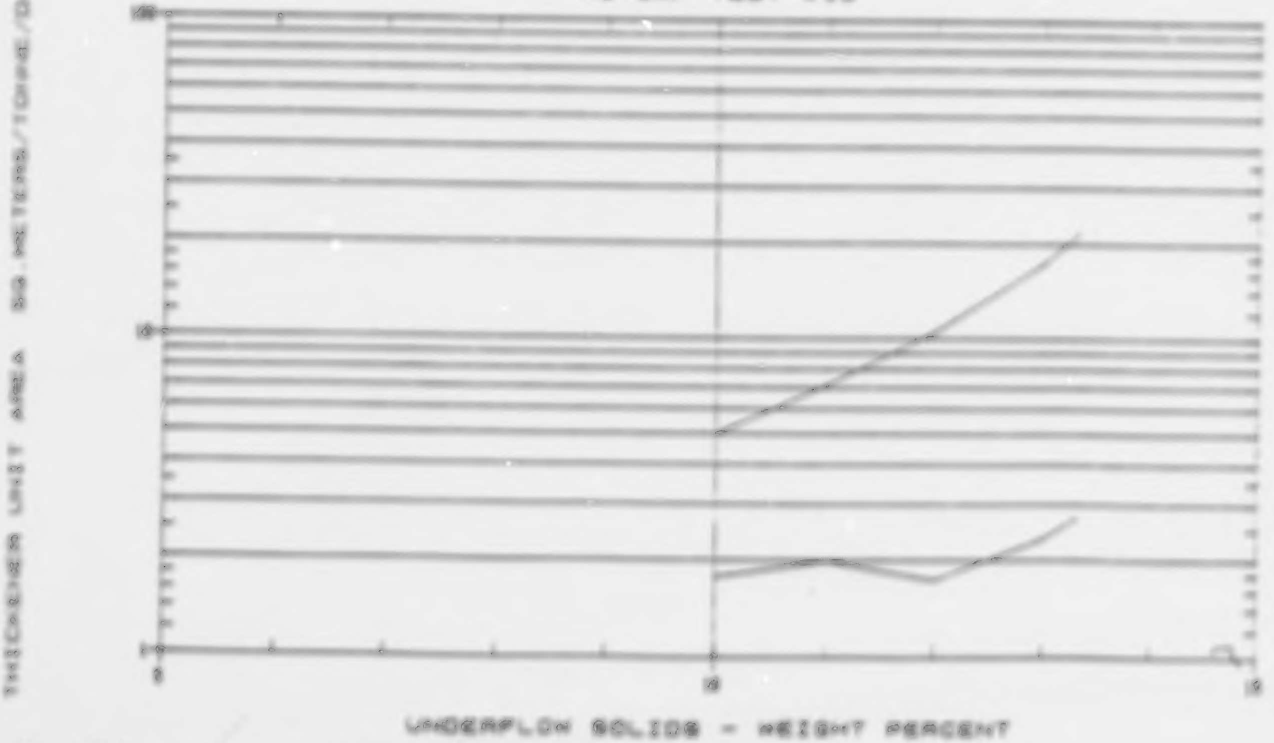


Figure __ UNIT AREA vs PCT. UF SOLIDS
MINATCO/MIDWEST
MI-CAP TEST #19



AUG 10. 1988 MINATCO/MIDWEST19

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                    EIMCO PROCESS EQUIPMENT COMPANY
                     THICKENER TEST SUMMARY SHEET

TEST ID: MINATCO/MIDWEST  TEST #70
      1ST. STAGE PRECIPITATE                              CREATED: Aug 18, 1997
                                                          UPDATED: Aug 18, 1997
STORAGE FILE: /ROBISON/WORK/MINATCO/MIDWEST70.THK
                                                            TIME (MIN)   WEIGHT (ML)
FLOCCULANT: PERCOL E-10                                         0.00        2000.
                              CONCENTRATION (G/L):   1.00        .50        1910.
                              VOLUME ADDED (ML):     1.0        1.00        1770.
                              DOSAGE:               14.0  G/MT  1.50        1610.
SETTLING VESSEL SIZE (ML/FT):  1690.                            2.00        1600.
UNDECANTED SLURRY VOLUME (ML): 2006.0                           3.00        1340.
           SLURRY WEIGHT (G):  3141.50   TARE (G): 1117.00      4.00        1060.
DECANTED SLURRY VOLUME (ML):    170.0                           5.00         940.
           SLURRY WEIGHT (G):  1186.10                          6.00         860.
DRY SOLIDS WEIGHT (G):          234.70   TARE (G):  205.30      7.00         760.
ULTIMATE INTERFACE HEIGHT (ML): 170.                           10.00         670.
                                                               12.00         570.
SPECIFIC GRAVITY SUPERNATANT     1.0000                        15.00         480.
SPECIFIC GRAVITY SOLIDS          2.7000                        20.00         370.
                                                               24.00         340.
UNDERFLOW CONCENTRATION    WEIGHT % SOLIDS      CU (MT/CU.M)   30.00         290.
   INITIAL                    1.05                 .01066      60.00         270.
   MINIMUM DESIRED            1.05                 .01066      75.00         210.
   FINAL (TEST)              12.84                 .13966     160.00         220.
   ULTIMATE                  14.05                 .16175     190.00         170.
                                                              *******      *******
                                                              *******      *******
   UNDERFLOW         UNDERFLOW         UNIT AREA       UNIT AREA          *******      *******
WEIGHT % SOLIDS    CU (MT/CU.M)      SQ.M/MTPD    SQ.M/MTPD CORRECTED     *******      *******
                                                              *******      *******
     12.8             .13940           22.195          2.676    *******      *******
     12.0             .12981           16.558          2.122    *******      *******
     11.0             .11818            9.611          1.677    *******      *******
     10.0             .10677            6.771          1.891    *******      *******
      9.0             .09541            3.665          1.706    *******      *******
      8.0             .08476            2.672          1.199    *******      *******
      7.0             .07371            2.221          1.760    *******      *******
      6.0             .06236            1.666          1.744    *******      *******
      5.0             .05162            1.368          1.679    *******      *******
      4.0             .04101            1.060           .908    *******      *******
      3.0             .03056             .766           .676    *******      *******
      2.0             .02024             .660           .427    *******      *******
                                                              *******      *******
                                                              *******      *******
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Figure __ BATCH INTERFACE SETTLING DATA
MINATCO/MIDWEST TEST #20
1ST. STAGE PRECIPATATE

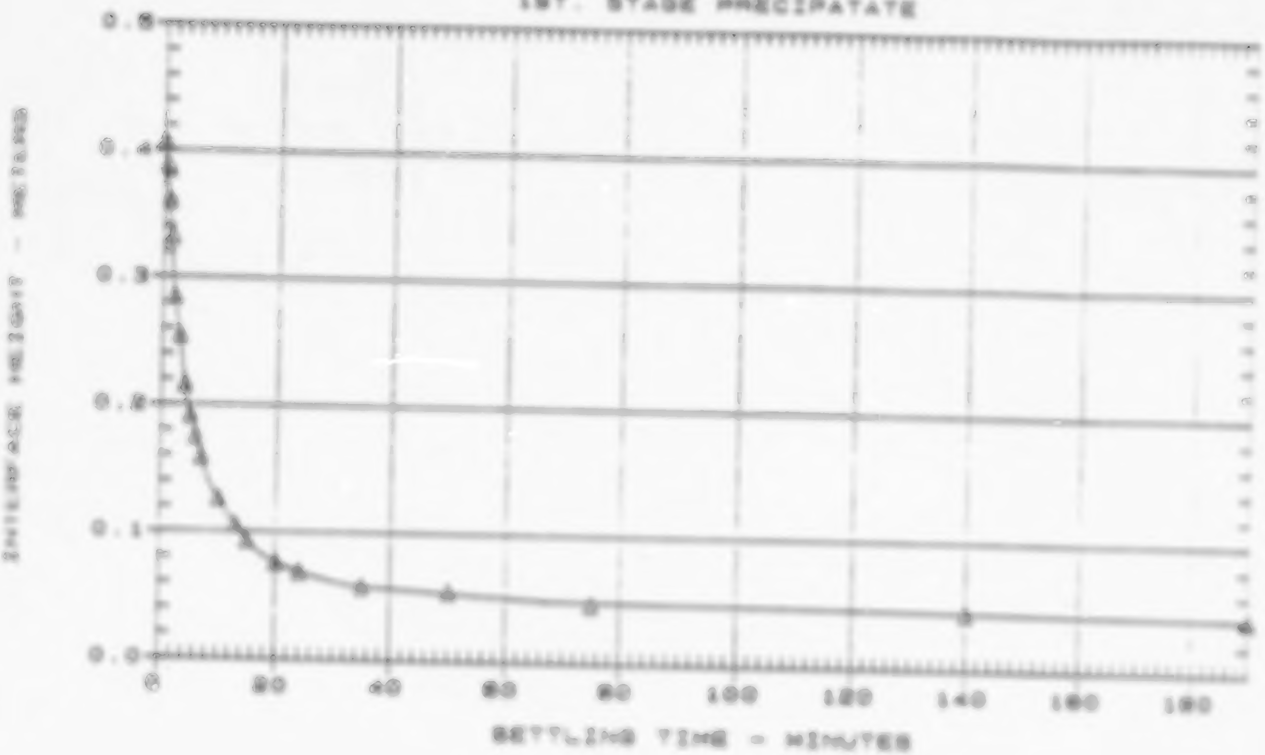
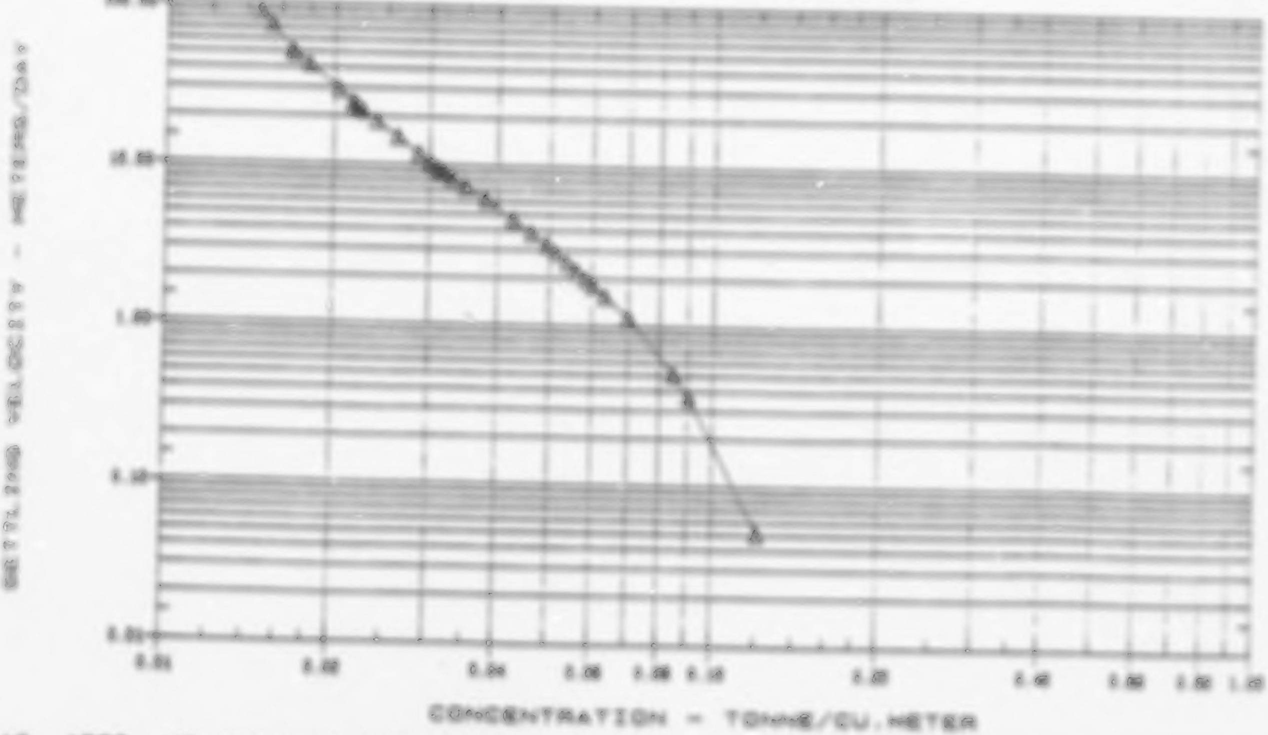


Figure __ SETTLING VEL vs CONCENTRATION
MINATCO/MIDWEST TEST #20
1ST. STAGE PRECIPATATE



AUG 10, 1992 MINATCO/MIDWEST20

Figure __ UNIT AREA vs UF CONCENTRATION
MINATCO/MIDWEST TEST #20
1ST. STAGE PRECIPATATE

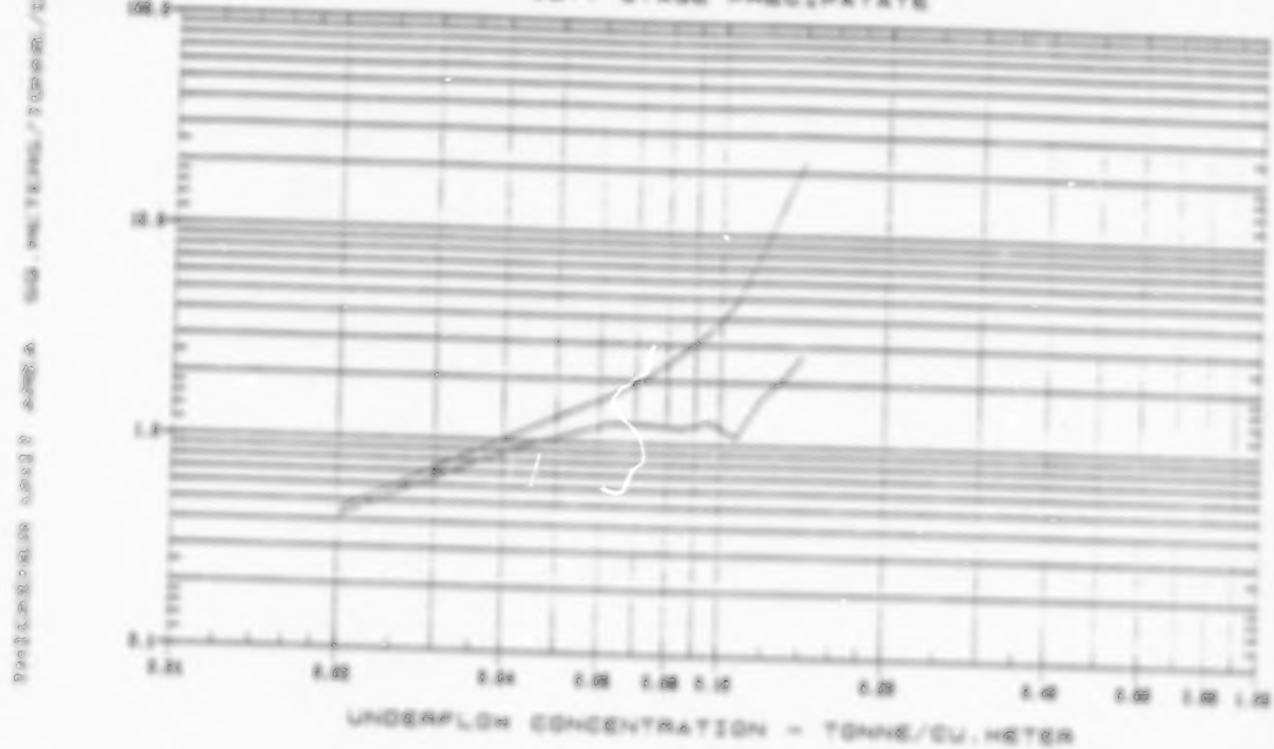
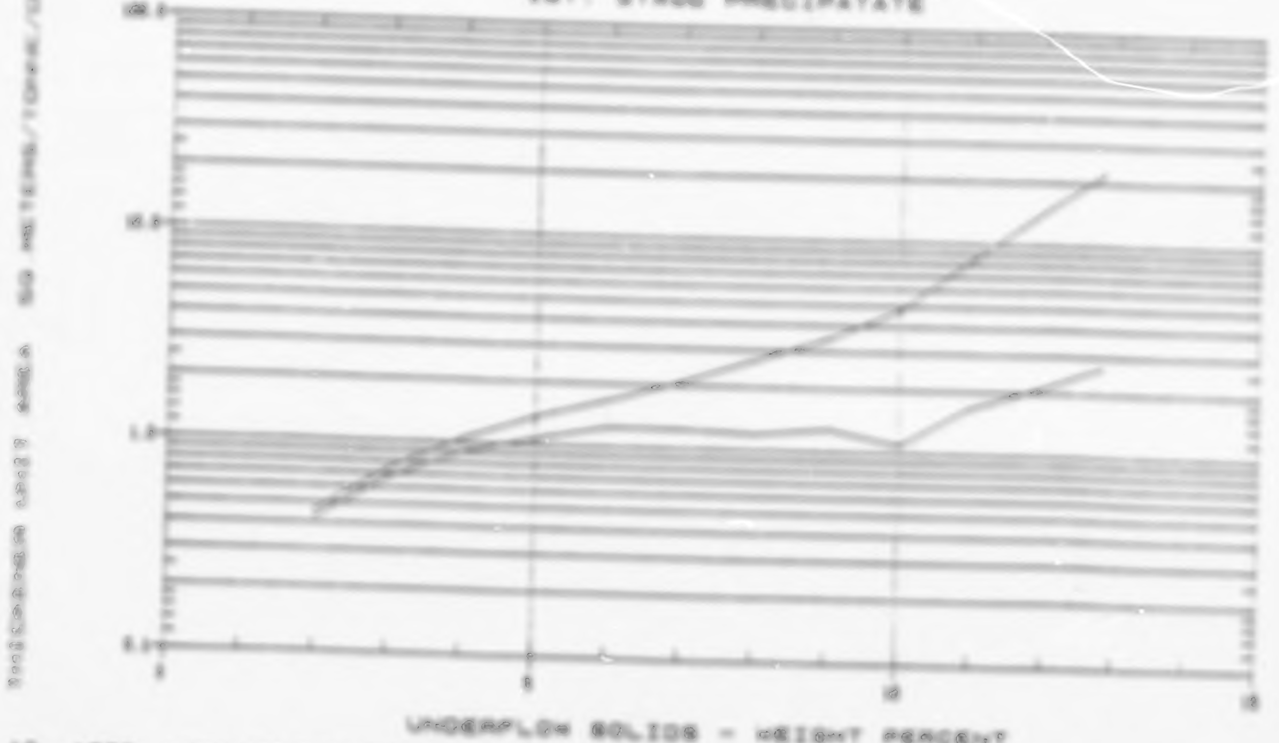


Figure __ UNIT AREA vs PCT. UF SOLIDS
MINATCO/MIDWEST TEST #20
1ST. STAGE PRECIPATATE



AUG 10, 1982 MINATCO/MIDWEST20

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                         EIMCO PROCESS EQUIPMENT COMPANY
                          THICKENING TEST SUMMARY SHEET

TEST ID: MINERALS/MICHIGAN TEST #71                              CREATED: Aug 18, 1997
       1ST. STAGE PRECIPITATE                                    UPDATED: Aug 18, 1997

STORAGE FILE: /[illegible]/MINERALS/MICHIGAN71.TMA
                                                                      TIME (MIN)    HEIGHT (ML)
FLOCCULANT: PERCOL E-10                                                   0.00         2000.
                                      CONCENTRATION (G/L):    1.00          .50         1870.
                                      VOLUME ADDED (ML):       1.5         1.00         1668.
                                      DOSAGE:                 47.0  G/MT   1.50         1462.
                                                                          2.00         1276.
SETTLING VESSEL SIZE (ML/HT):    1937.                                    3.00          970.
UNDECANTED SLURRY VOLUME (ML):   2000.1                                   4.00          815.
           SLURRY WEIGHT (G):    2121.69    TARE (G): 1101.70             5.00          718.
DECANTED SLURRY VOLUME (ML):      142.7                                   7.00          508.
           SLURRY WEIGHT (G):    1288.76                                 16.00          308.
DRY SOLIDS WEIGHT (G):            156.10    TARE (G):  118.28            37.00          240.
ULTIMATE INTERFACE HEIGHT (ML)    170.                                   67.00          218.
                                                                        122.00          195.
SPECIFIC GRAVITY SUPERNATANT         1.0000                             175.00          180.
SPECIFIC GRAVITY SOLIDS              2.7010                            *******       *******
                                                                       *******       *******
UNDERFLOW CONCENTRATION        WEIGHT % SOLIDS          CU (MT/CU.M)   *******       *******
   INITIAL                           1.28                   .01297     *******       *******
   MAXIMUM (DESIGN)                  1.28                   .01297     *******       *******
   FINAL (TEST)                     15.17                   .14998     *******       *******
   ULTIMATE                         13.08                   .15701     *******       *******
                                                                       *******       *******
     UNDERFLOW            UNDERFLOW          UNIT AREA          UNIT AREA              *******       *******
  WEIGHT % SOLIDS       CU (MT/CU.M)      SQ.M/(MT/D)   SQ.M/(MT/D) CORRECTED          *******       *******
                                                                       *******       *******
       15.2               .14998            16.668            2.409    *******       *******
       15.0               .16190            27.024            2.704    *******       *******
       12.4               .13981            11.471            1.376    *******       *******
       11.3               .11819             6.976            1.878    *******       *******
       10.4               .10677             8.141             .830    *******       *******
        9.8               .09960             3.831             .846    *******       *******
        8.8               .08876             2.167             .946    *******       *******
        7.8               .07723             1.778            1.193    *******       *******
        6.8               .06716             1.477            1.195    *******       *******
        5.8               .05161             1.203             .974    *******       *******
        4.8               .04155              .872             .687    *******       *******
        3.8               .03096              .594             .657    *******       *******
        2.8               .02016              .743             .768    *******       *******
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Figure __ BATCH INTERFACE SETTLING DATA
MINATCO/MIDWEST TEST #01
1ST. STAGE PRECIPITATE

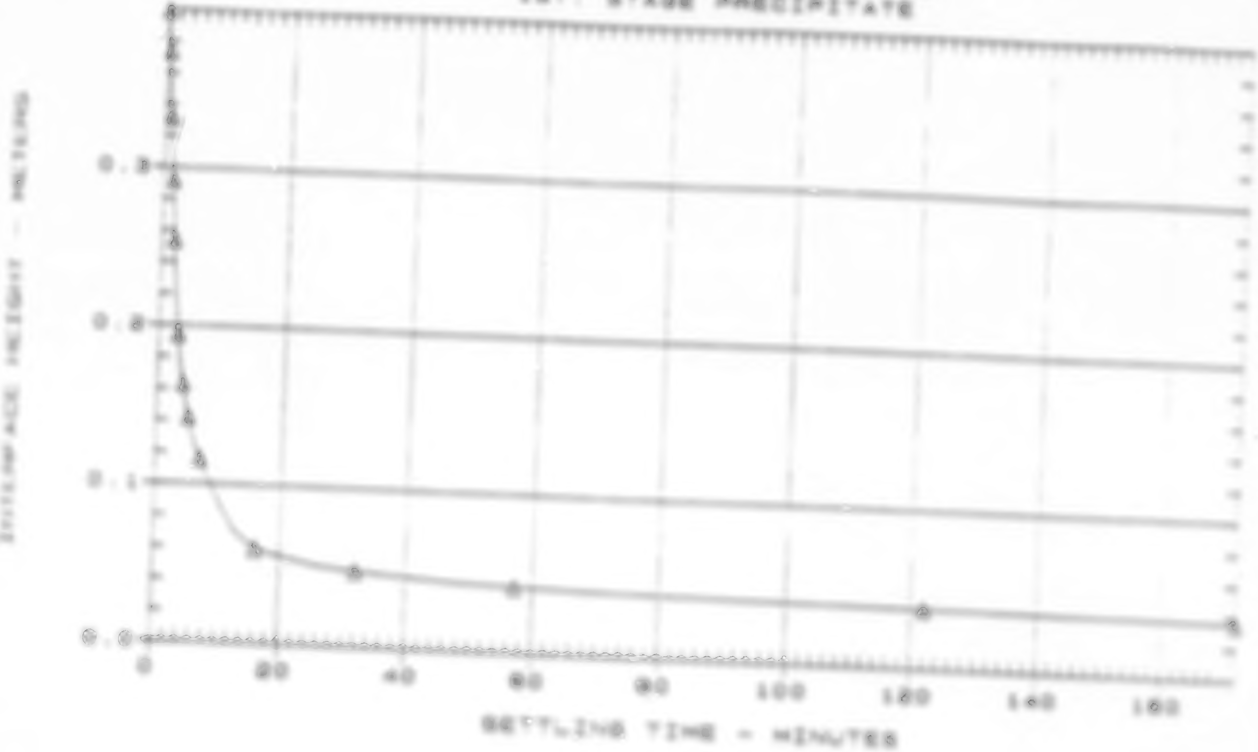
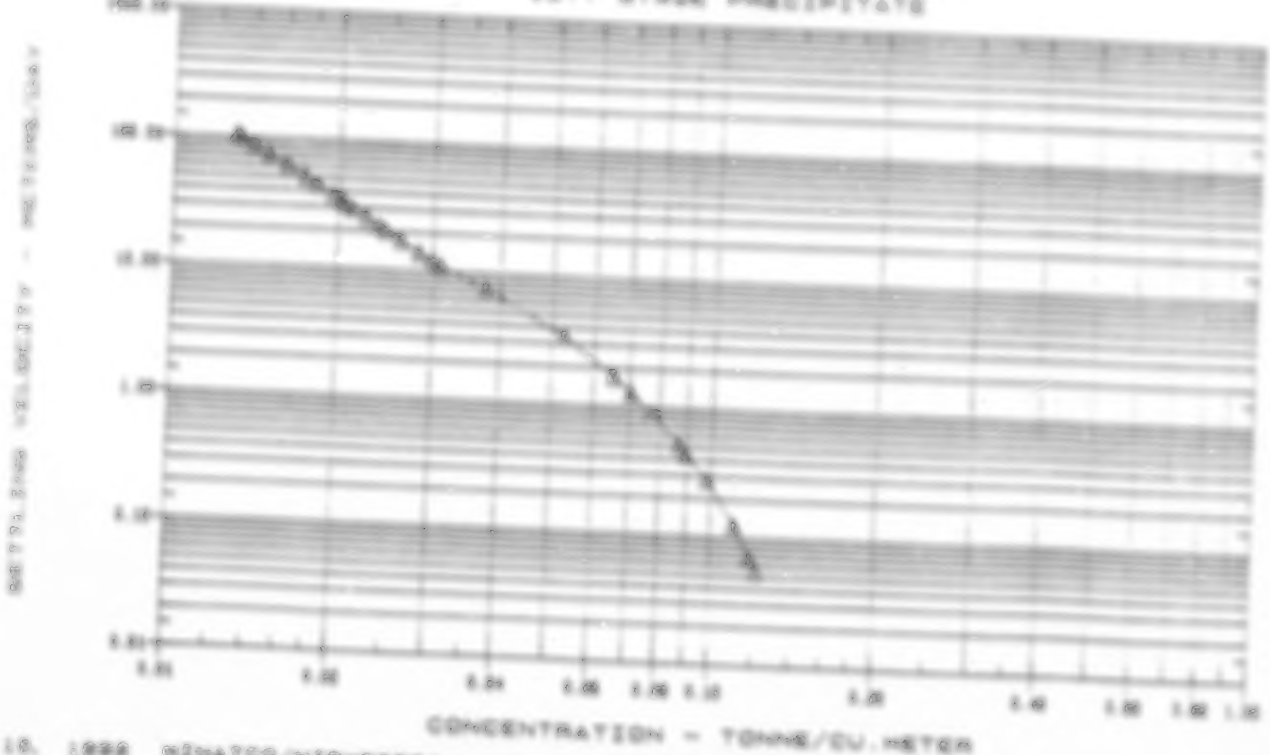


Figure __ SETTLING VEL VS CONCENTRATION
MINATCO/MIDWEST TEST #01
1ST. STAGE PRECIPITATE



AUG 10, 1988 MINATCO/MIDWEST01

Figure __ UNIT AREA vs UF CONCENTRATION
MINATCO/MIDWEST TEST #21
1ST. STAGE PRECIPITATE

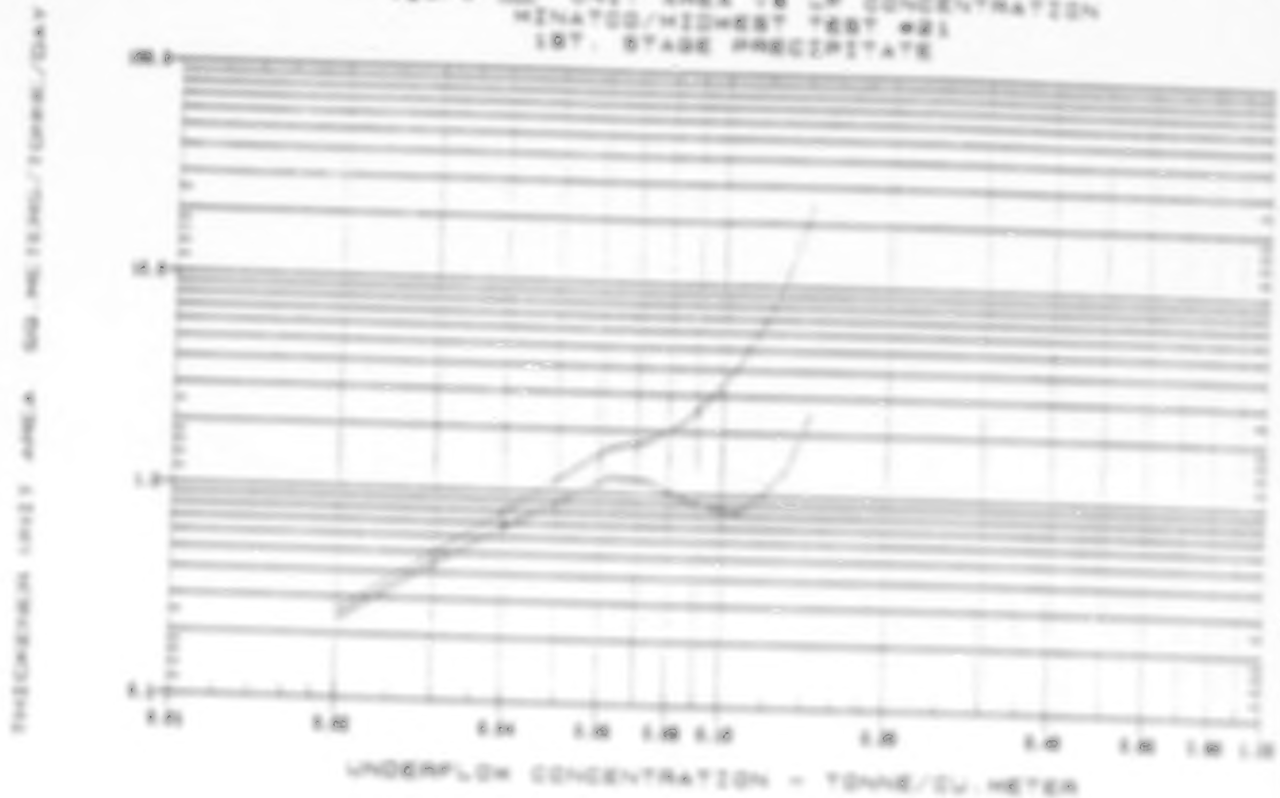
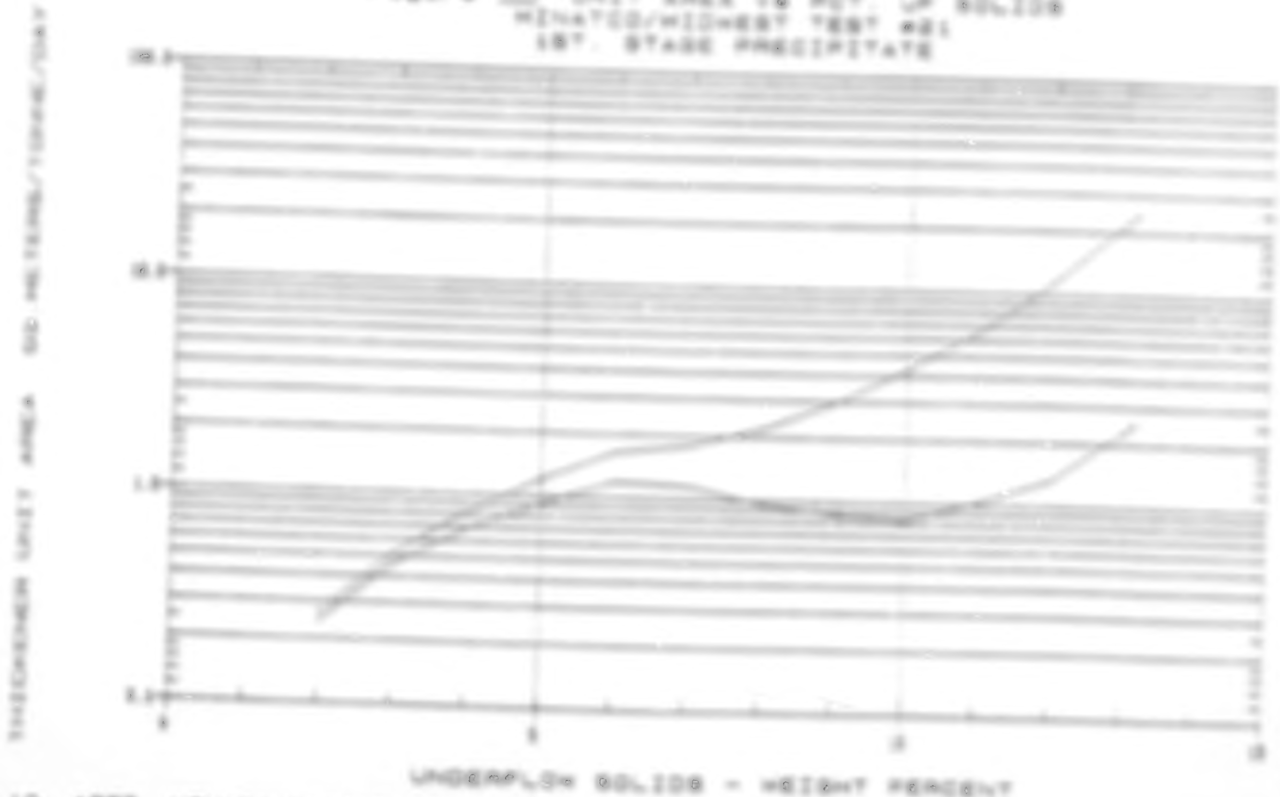


Figure __ UNIT AREA vs PCT. UF SOLIDS
MINATCO/MIDWEST TEST #21
1ST. STAGE PRECIPITATE



AUG 15, 1988 MINATCO/MIDWEST21

SECTION 3.0

1st-STAGE PRE-TREATMENT PRECIPITATA FILTRATION

DISCUSSION AND CONCLUSIONS

SECTION 3.0 - DISCUSSION & CONCLUSIONS

B) 1st-Stage Pre-Treatment Filtration

EIMCO conducted a total of sixteen (16) standard bench-scale top feed filtration tests on 1st-Stage Pre-Treatment precipitate slurry sample prepared by Lakefield research. All of these filtration tests were conducted applying EIMCO standard top feed filtration techniques. A sketch of the testing apparatus is attached to this report for your reference. Generally, the filtration testing technique was as follows. A measured volume of slurry sample, appropriate for the desired cake thickness was poured onto the filter leaf surface. The area of the test leaf is 0.1 ft^2 or 92.9 cm^2. Vacuum was applied by opening the ball valve to the filtrate receiver, at the desired vacuum level. The time required to form the filter cake was recorded. Various quantities of cake wash water were applied and the wash time recorded. Then the filter cake was air dried for predetermined times and that time was recorded. The formed filter cake was discharged from the filter leaf and the wet weight and cake thickness recorded. The filter cakes were oven dried. After final drying, the dry cake was weighed. For the filter cake washing tests the cakes were repulped and refiltered and the filtrate analyzed for soluble nickel remaining.
This data was recorded on the attached 'raw data sheet' for each of the tests. The data was correlated and these results plotted on graphs for final filter sizing. The correlated data and graphs are attached for your reference.

Feed Solids Concentration

The test slurry was thickened to a back calculated average feed solids concentration of approximately 15 weight percent. This slurry thickened to that density. We would expect filter feed densities in the 15 to 20 weight percent range. The filter has been sized on the lower feed solids concentration of 15 wt%. Of coarse the higher feed solids concentration to the filter will reduce the form time and overall filter cycle and therefore, increase the full scale filtration rate.

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

SECTION 3.0 - DISCUSSION & CONCLUSIONS

B) 1st-Stage Pre-Treatment Filtration

Filter Cake Washing

Following the form portion of the filter cycle the filter cake was washed with tap water to remove soluble nickel and cobalt. Most of the filter tests were run with a cake wash. Tests 6 to 11 were run with wash ratios ranging from 2.83 to 0.33. After the dry portion of the filter test the cake were removed from the test leaf and repulped in 100 mls of tap water. The solids were again filtered on a buchner funnel and that filtrate analyzed for remaining concentrations of soluble nickel to define the wash efficiency of this material. Figure 5 is a graphical representation of the wash efficiency. At a wash ratio of approximately 3.0 the efficiency is about 80%. The wash water requirement is approximately 4.64 kgs of wash water per kg of dry solids. The overall soluble nickel recovery based upon the process conditions applied is 99.6%.

Filter Cake Drying

The final operation in the filter cycle is the cake dewatering and drying. Typically, this gypsum cake cracked during the dry portion of the filtration cycle. The filter cakes reached a final cake moisture of approximately 64 weight percent. During the drying portion of the filter cycle the vacuum level dropped off from 508 to around 381 mm Hg. As soon as the filter cake cracks the filter cakes have reached a final weight percent moisture and very little additional reduction in moisture is obtained. At this point the vacuum air flow increases significantly. Since there is little benefit to the final cake moisture at this point in the filter cycle filtration should be terminated. It will be necessary to control the final dry time and cake cracking to prevent reducing the vacuum in the form and wash portions of the filter cycle which would affect the filter performance in these areas. The vacuum pump should be sized based upon 2.44 $m^3/min/m^2$, or 8 cfm/ft^2 at 508 mm Hg.

SECTION 3.0 - DISCUSSION & CONCLUSIONS

B) 1st-Stage Pre-Treatment Filtration

Filter Configuration

All of the filter tests were conducted simulating the top feed horizontal belt filter. This filter configuration was requested at the outset of the test work. The EIMCO-Extractor, horizontal belt filter configuration is selected for applications where the solids specific gravity is high, there is a coarse solid size, and the slurry has a fast form rate, or filter cake washing is required. In this application the iron/gypsum slurry filters relatively fast and efficient filter cake washing is required. While this filter configuration is more expensive than the standard vacuum drum filter there certainly is no better washing machine than the horizontal belt filter.

Based upon a filter feed rate of 2.63 tonnes per hour and a full-scale filtration rate of 84 $kg/m^2.h$ *we recommend an EIMCO-Extractor, model 3M30, horizontal belt filter. This filter will provide 30* m^2 *of effective filtration area.*

MIDWEST JOINT VENTURE

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

EIMCO PROCESS EQUIPMENT

FILTRATION SUMMARY SHEETS

COMPANY: MIDWEST JOINT VENTURE
ADDRESS: SASKATOON, SASKATCHEWAN
MATERIAL: 1st STAGE PRECIPITATE

DATED TESTED: JULY 8, 1992
BY: W.W. STONE

FEED % SOLID: AS TESTED BELOW
FILTRATION AREA: 0.1 ft2

LIQ. SG: 1.0
SLURRY SG: BELOW
SOLIDS SG: 2.8
FILTER MEDIA: POLYPROPYLENE 929

pH: 3.2
TOP FEED TESTING: YES
VACUUM AIR LEAKAGE 0.065
AIR FLOW MEASURED BY GAS METER: YES

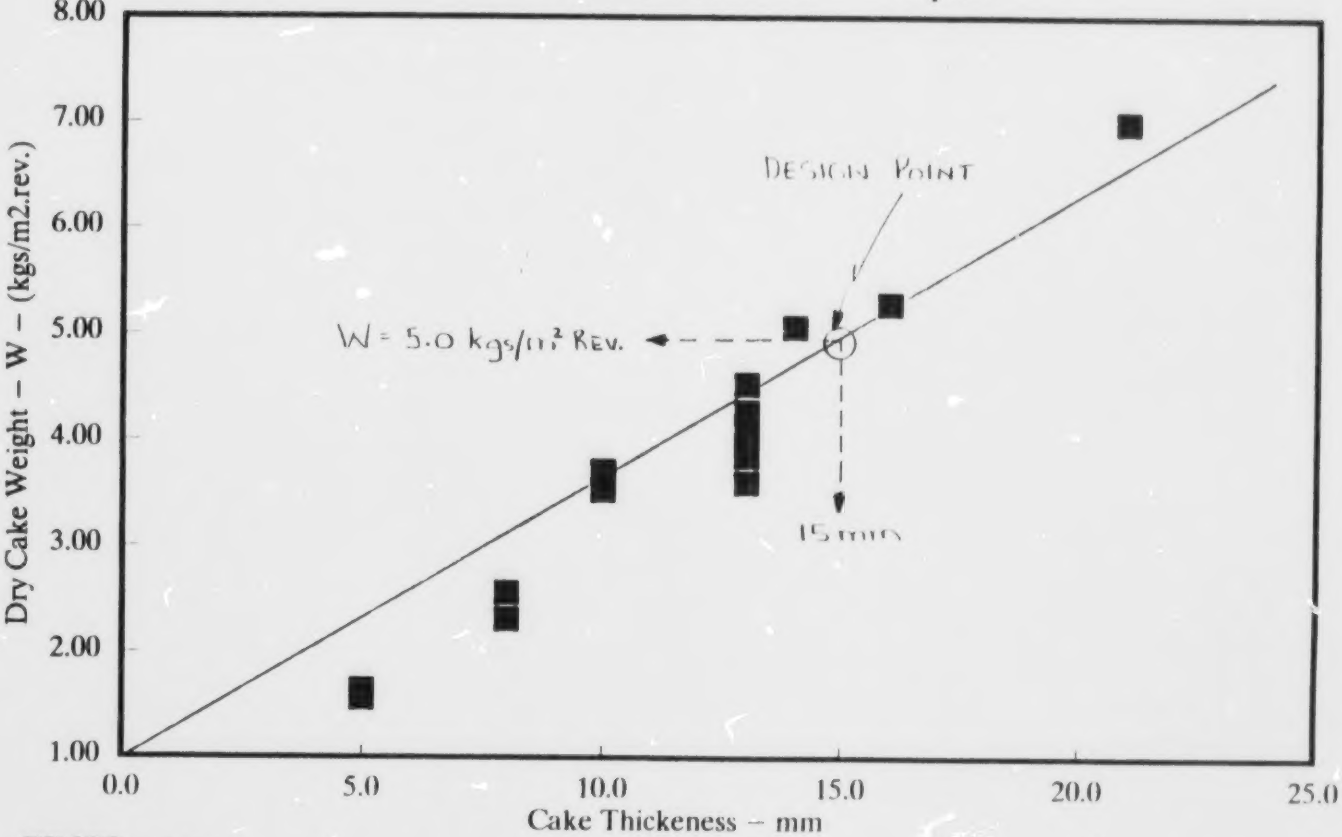
CORRELATED FILTRATION DATA

TEST NO.	1	2	3	4	5	6	7	8	9	10	[illegible]	12	13	14	15	16
FORM VACUUM (mm Hg)	508	508	508	508	508	508	508	508	508	508	[illegible]	508	381	381	381	381
WASH VACUUM (mm Hg)	508	508	508	508	508	508	508	508	508	508	508	508	381	381	381	381
DRY VACUUM (mm Hg)	406	381	381	381	381	406	406	406	406	406	406	406	381	381	381	381
FORM TIME (seconds)	32	14	8	46	3	14	15	14	15	15	14	16	4	6	11	19
WASH TIME (seconds)	36	23	13	55	5	63	47	29	25	16	8	0	5	13	21	33
DRY TIME – (seconds)	30	15	60	30	60	30	30	30	30	30	30	30	120	90	60	30
AIR READING BEFORE (ft3)	0.18	0	0	0.78	0.65	0.81	0.3	0.68	0.07	0.3	0.55	0.77	0	0.5	0.4	0.45
AIR READING AFTER (ft3)	1.37	0	0	1.45	1.54	2.07	1.5	1.84	1.1	1.4	1.62	1.48	0	2.3	2.28	1.5
TOTAL FILTR VOLUME (mls)	244	182	132	338	78	350	300	242	226	198	174	162	90	146	200	274
WASH VOLUME (mls)	75	60	40	100	20	200	150	100	75	50	25	0	20	50	75	100
CAKE THICKNESS (mm)	14	10	8	21	5	13	13	13	13	13	13	13	5	8	10	16
TARE WEIGHT (gms)	165.9	160	168.2	173	169.5	167.1	10.85	10.84	10.9	10.9	10.63	211.7	80.9	92.4	136.5	[illegible]
TOTAL WET CAKE WT. (gms)	295.6	249.7	231.1	350.9	207.5	276.2	123.8	121.2	126.5	125.4	125.5	330.9	120.1	154.8	229.9	227
TOTAL DRY CAKE WT (gms)	213	192.8	192	238.1	184	205.6	47.6	44.3	53	46.7	50.3	249.6	96.2	113.9	171	139.1
ASSAYED FILTER CAKE RESIDUE Ni (mg/l)						63.9	79.5	105	158	278	410					
NET WET CAKE WT. (gms)	129.7	89.7	62.9	177.9	38	109.1	112.95	110.36	115.6	114.5	114.87	119.2	39.2	62.4	93.4	137.2
NET DRY CAKE WT (gms)	47.1	32.8	23.8	65.1	14.5	38.5	36.75	33.46	42.1	35.8	39.67	37.9	15.3	21.5	34.5	49.1
FINAL CAKE MOISTURE (wt.%)	63.69	63.43	62.16	63.41	61.84	64.71	67.46	69.68	63.58	68.73	65.47	68.20	60.97	65.54	63.06	64.21
AIR FLOW (m3/min/m2)	7.06	−0.20	−0.20	3.89	2.52	7.49	7.13	6.88	6.09	6.51	6.33	4.13	−0.20	3.46	5.54	6.21
BACK CAL'D FEED SOLIDS (wt%)	15.77	15.49	15.36	15.65	15.10	14.86	13.98	13.26	15.79	13.64	15.03	13.48	14.01	13.57	15.80	15.78
W – CAKE LOADING (kg ds/m2)	5.07	3.53	2.56	7.00	1.56	4.14	3.95	3.60	4.53	3.85	4.27	4.08	1.65	2.31	3.71	5.28
DRY CORR. FACTOR (min – m2/kg)	0.10	0.07	0.39	0.07	0.64	0.12	0.13	0.14	0.11	0.13	0.12	0.12	1.21	0.65	0.27	0.09
ACTUAL FILTER CAKE RESIDUAL Ni (mg/l)						154.41	183.83	241.54	372.97	631.24	955.21					
FRACTION Ni SOLUTE REMAINING – R						0.13	0.15	0.20	0.31	0.52	0.79					
N (no. wash displ.)	0.91	1.05	1.02	0.89	0.85	2.83	1.97	1.30	1.02	0.64	0.33	0.00	0.84	1.22	1.27	1.14
WW (kgs – l)/m4	40.90	22.79	11.02	75.37	3.36	89.15	63.82	38.74	36.56	20.72	11.48	0.00	3.54	12.45	29.96	56.85
PLOT SYMBOL NBR	1	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4
WASH TIME ('mins')	0.60	0.38	0.22	0.92	0.08	1.05	0.78	0.48	0.42	0.27	0.13	0.00	0.08	0.22	0.35	0.55
FORM TIME (mins.)	0.53	0.23	0.13	0.77	0.05	0.23	0.25	0.23	0.25	0.25	0.23	0.27	0.07	0.10	0.18	0.32
DRY TIME (mins)	0.50	0.25	1.00	0.50	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	2.00	1.50	1.00	0.50

EIMCO/wws

MIDWEST JOINT VENTURE

1st – STAGE PRECIPITATE   Fiqure 1



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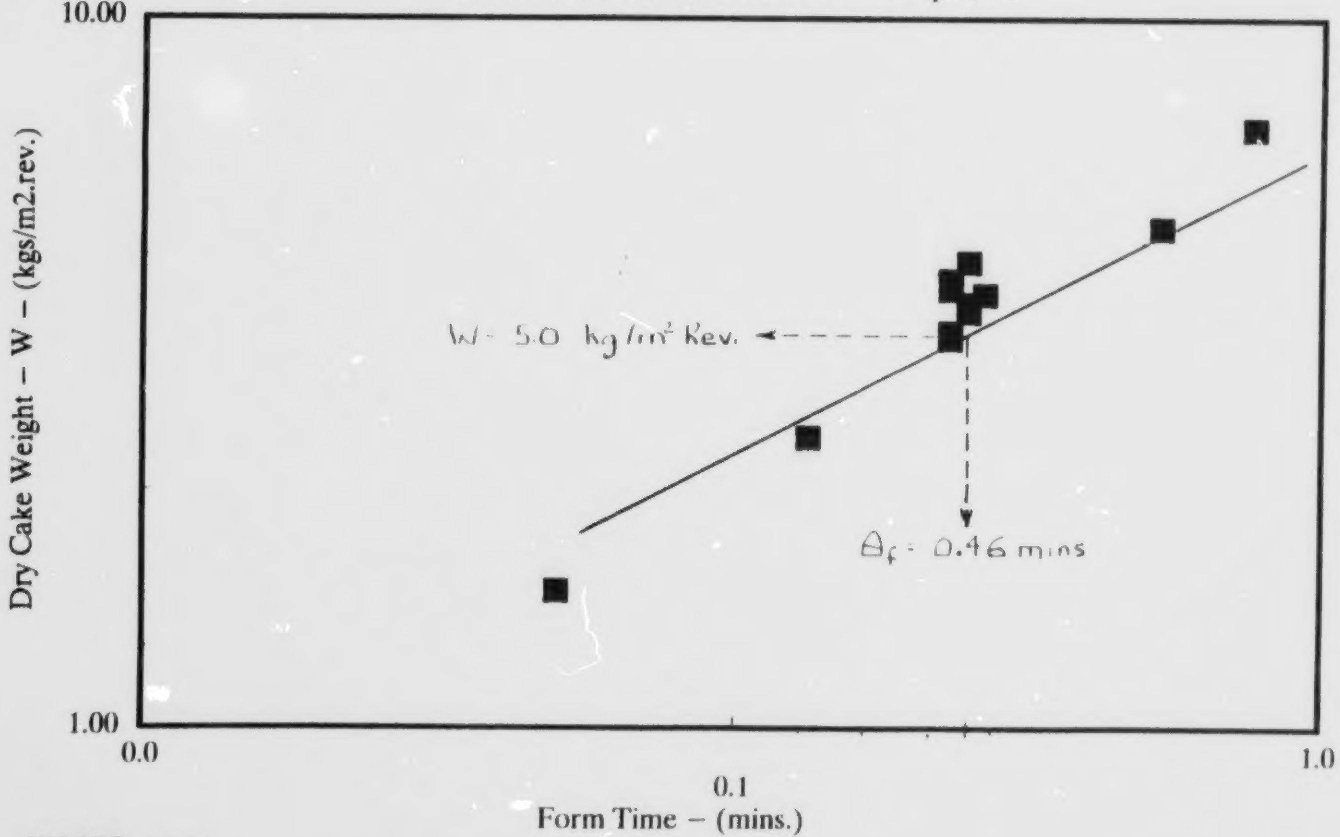
August 18, 1992

MIDWEST JOINT VENTURE

1st–STAGE PRECIPITATE Fiqure–2



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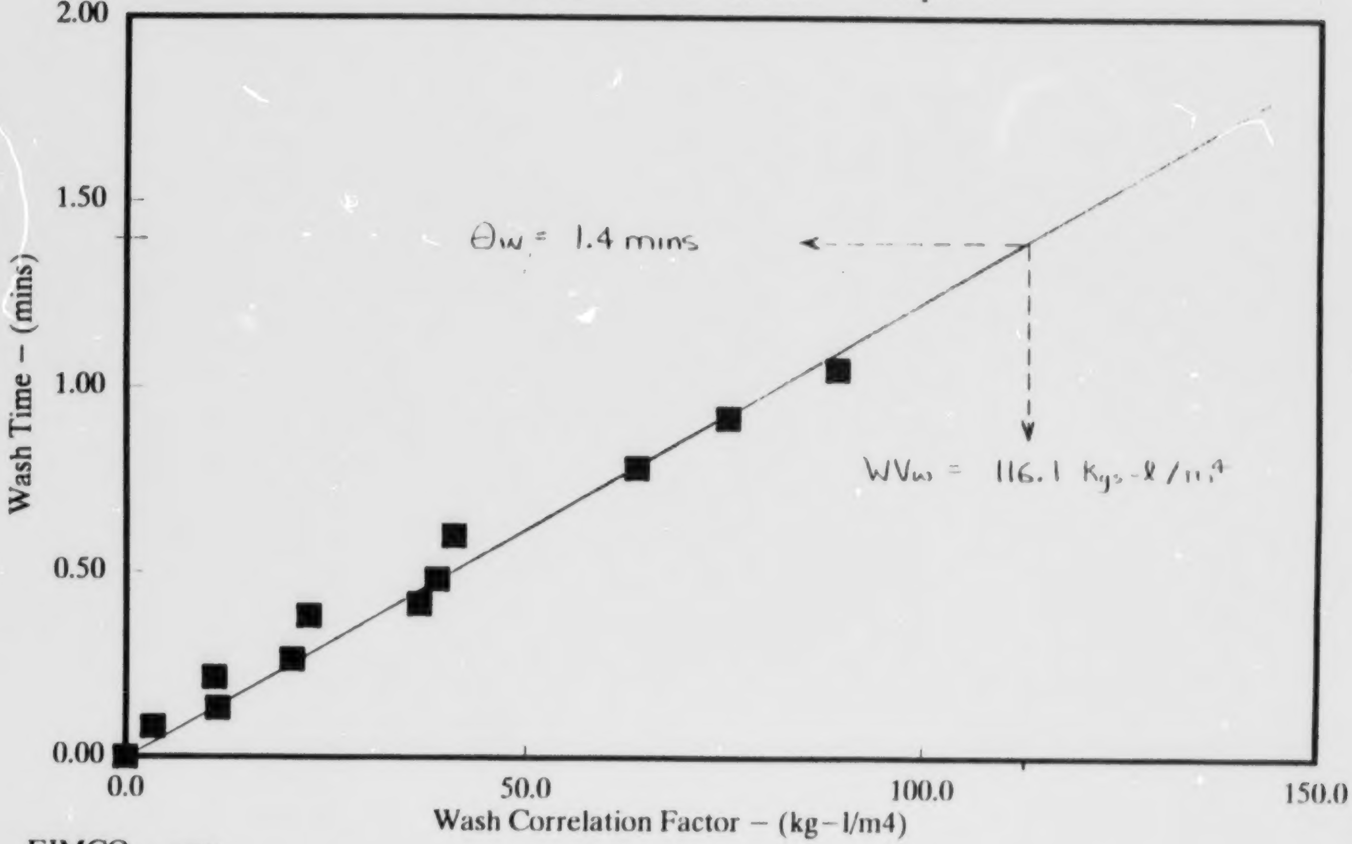
MIDWEST JOINT VENTURE

1st–STAGE PRECIPITATE Fiqure–3



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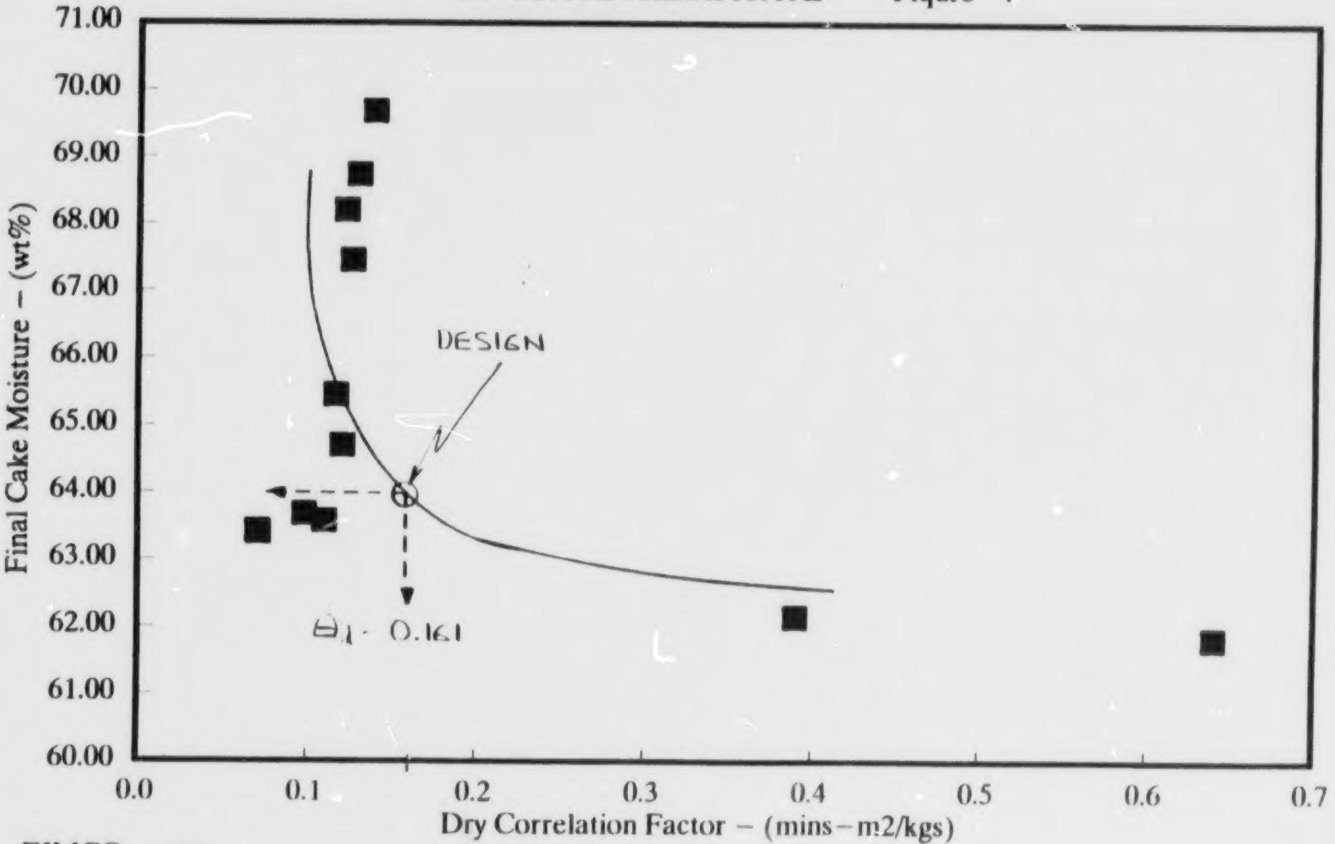
MIDWEST JOINT VENTURE

1st–STAGE PRECIPITATE Fiqure–4



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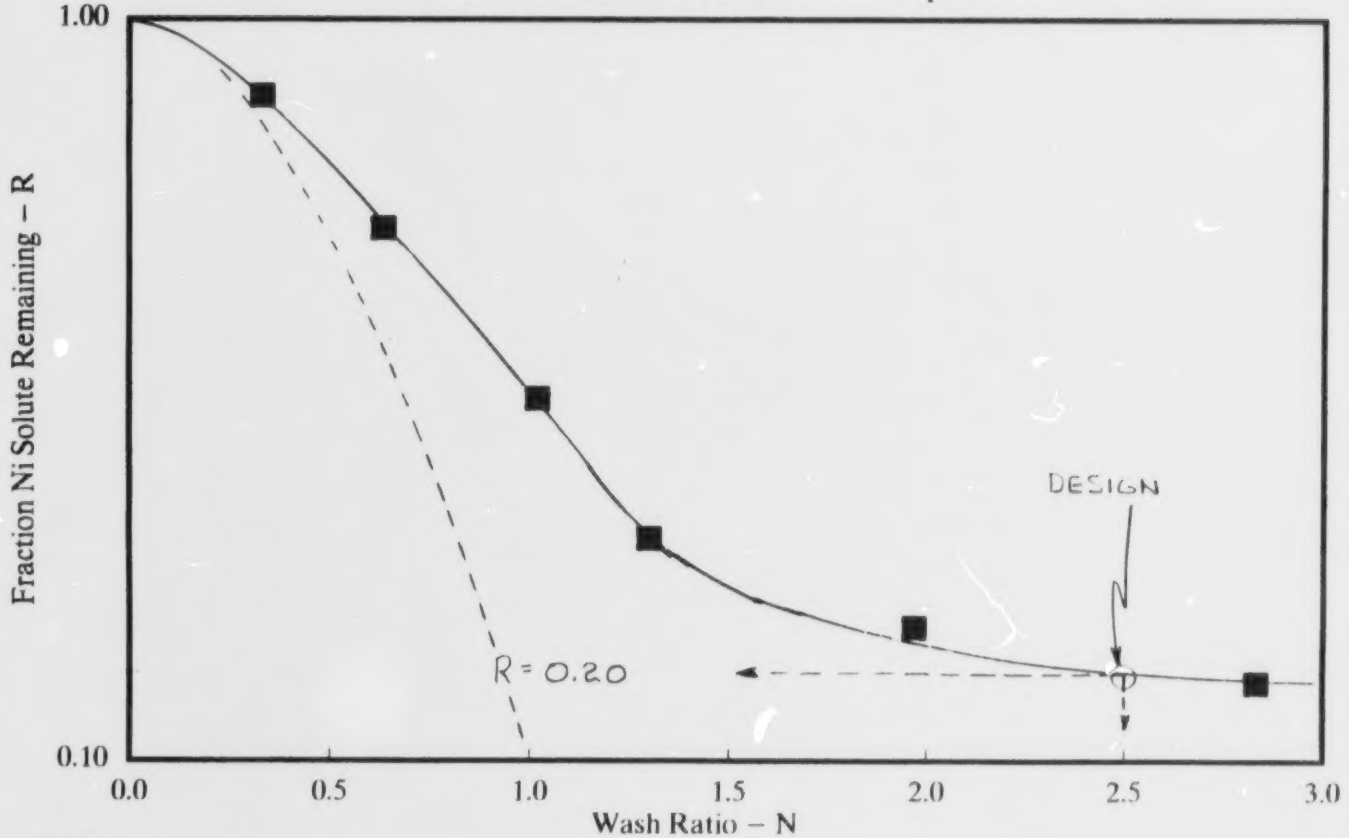
MIDWEST JOINT VENTURE

1st–STAGE PRECIPITATE Fiqure – 5



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August 18, 1992

MIDWEST JOINT VENTURE

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION
1st-STAGE PRECIPITATE FILTRATION

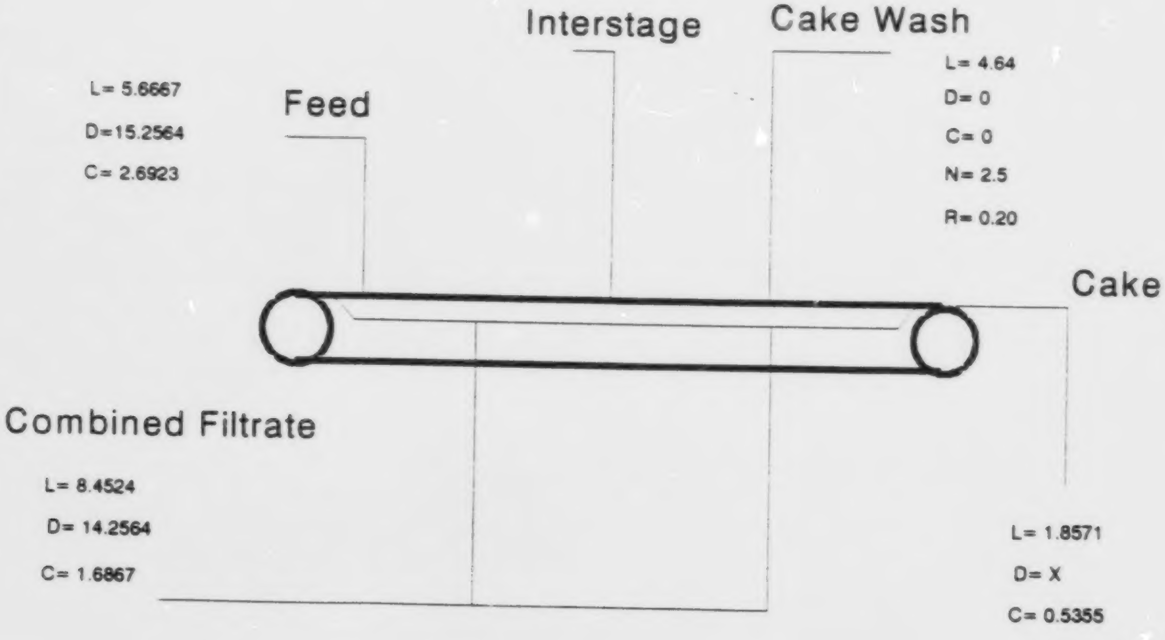
EIMCO PROCESS EQUIPMENT

EIMCO-EXTRACTOR HORIZONTAL BELT FILTER
MATERIAL BALANCE FOR DETERMINATION OF THE FILTER WASH EFFICIENCY

Process Conditions:		
	Feed Tonnage-	2.63
	Feed Solids Conc. -	15
	Filter Cake Moist. -	65
	Filter Cake Wash Ratio-	2.5
	Wash Efficiency R-	0.2
	Interstage Cake Moist. -	65

	FILTER FEED	INTERSTAGE	CAKE WASH	STRONG FILTRATE	WASH FILTRATE	COMBINED FILTRATE	FILTER CAKE
L	5.6667	1.8571	4.6429	3.8095	4.6429	8.4524	1.8571
D	15.2564	5.0000	0.0000	10.2564	4.0000	14.2564	x
C	2.6923	2.6923	0.0000	2.6923	0.8615	1.6867	0.5385
N			2.5000				
R			0.2000				

PERCENT RECOVERY: 99.6286



Interstage
Cake Wash
L= 5.6667
D=15.2564
C= 2.6923
Feed
L= 4.64
D= 0
C= 0
N= 2.5
R= 0.20
Cake
Combined Filtrate
L= 8.4524
D= 14.2564
C= 1.6867
L= 1.8571
D= X
C= 0.5355

EIMCO-EXTRACTOR, HORIZONTAL BELT FILTER

SOLUTE PERCENT RECOVERY = 99.63

EIMCO/wws

SECTION 3.0

2nd-STAGE PRE-TREATMENT PRECIPITATE CLARIFICATION

DISCUSSION AND CONCLUSIONS

SECTION 3.0 - DISCUSSION & CONCLUSIONS

C) 2nd-Stage Pre-Treatment Clarification

For this 2nd-Stage Pre-Treatment Clarifier application we ran conventional thickening and clarification tests on a sample as received from the Lakefield Research. One standard thickening test was run with flocculant added. This slurry settled very well except that the supernatant was dirty so clarification tests were conducted to define the rise rate as it may control the thickener sizing. Four (4) clarification tests were run on the same sample as used for the thickening test.

The thickening test procedure applied was per the above description for the 1st-Stage Pre-Treatment slurry. In this application I only ran one thickening test. Clarification test work is carried out in a 4 litre glass beaker fitted with a variable speed mixer. The sample is mixed and flocculant is added to the slurry and mixed slowly for a period of 10-20 seconds. Samples of the liquor are withdrawn at a certain depth at various settling times. The samples are analyzed for suspended solids. From the time and sampling depth the rise rate is calculated and it is plotted versus the suspended solids. Attached are the data tables and graphs for the four clarification tests.

From the results of this testing we have provided the thickener sizing based upon the design unit area reported as m^2*/tonne/day and the design rise rate, reported as L/min/*m^2*. Since the feed solids rate to this clarifier is relatively low the thickener sizing is controlled by the rise rate.*

Flocculant Type and Dosage

In this thickening and clarification test work Allied Colloid's Percol E-10 was used. From the clarification tests we determined that a flocculant dosage of approximately 0.50-1.0 mg/L is required. The clarification tests were run with flocculant dosages ranging from 0.5 to 0.75 mg/L. In all cases the material flocculated very well however the higher flocculant dosage and solids concentration gave better clarification results.

SECTION 3.0 - DISCUSSION & CONCLUSIONS

C) 2nd-Stage Pre-Treatment Clarification

Slurry Flocculant Mixing Intensity

Adding flocculant to the feed slurry and the appropriate mixing of this slurry is of course important to obtain effective flocculation. In the clarification testing we applied a flash mix for approximately 10 seconds and a floc mix for 20 seconds. Consideration should be given to the EIMCO Reactor-Clarifier to provide the type of flocculant and slurry mixing to minimize the suspended solids reporting to overflow.

Thickener Underflow Solids Concentration

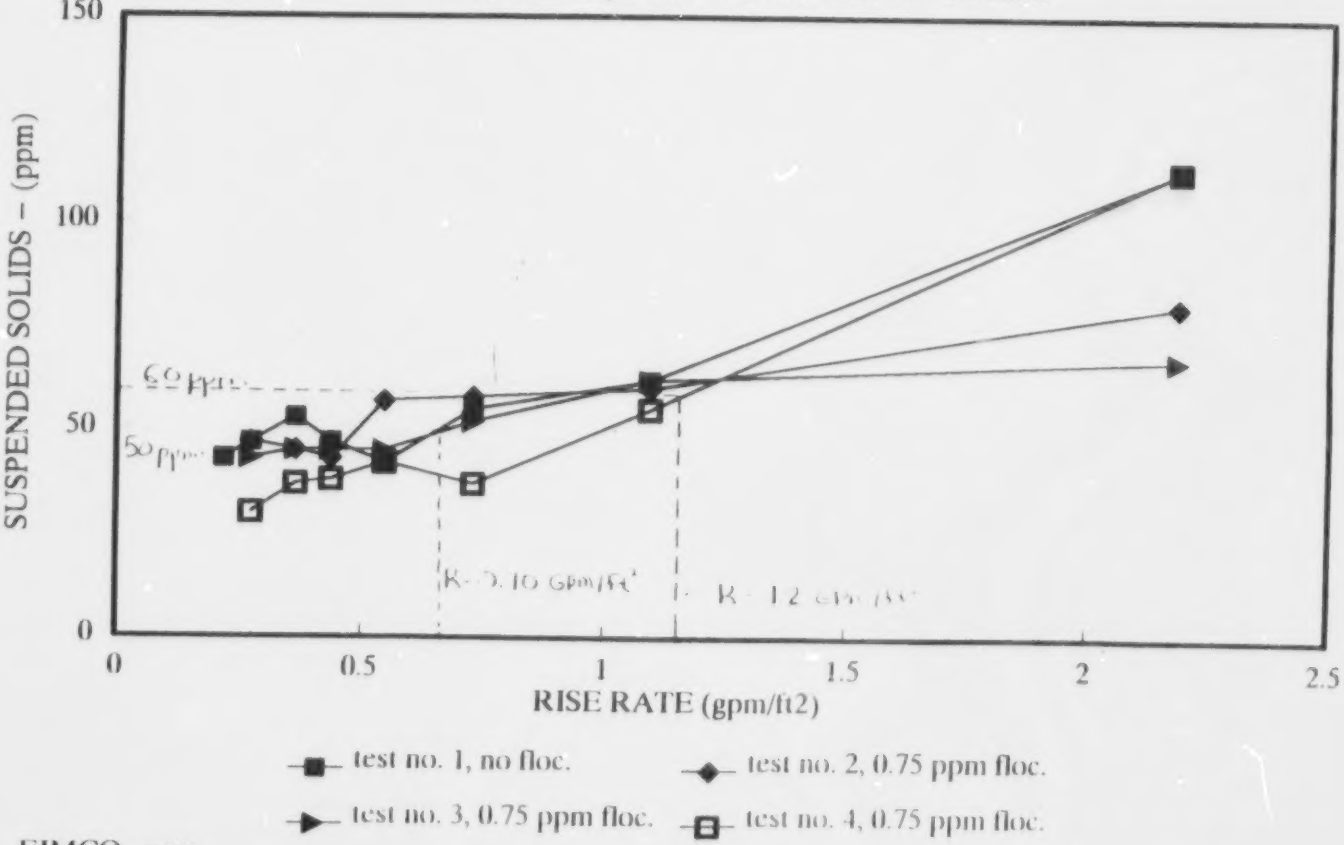
From the thickening tests the final solids concentration was 8.6 weight percent solids. We can expect clarifier underflow solids concentrations in the 10-15 wt% range. However, the underflow pumping system should be capable of pumping the lower sludge densities, 5 wt% would be a minimum solids concentration and require the maximum pumping capacity.

Feed Solids Concentration

The slurry was tested at the feed solids concentration ranging from 0.5 to just over 1 wt% in the clarification test work. Comparing all of these tests the test No. 4 was better than the others. This is attributed to the higher feed solids concentration, approximately 1 wt%. Since the feed to this clarifier will only be at 0.1 wt % it will be important to introduce sludge into the clarifier feed stream. We recommend that an EIMCO Reactor clarifier be considered for this application with the internal sludge recirculating turbine.

MIDWEST JOINT VENTURE

Ni/Co Recovery From Midwest Raffinate Solution



EIMCO – wws
August 21, 1992

MIDWEST JOINT VENTURE

AUGUST 21, 1992

SASKATOON, SASKATCHEWAN

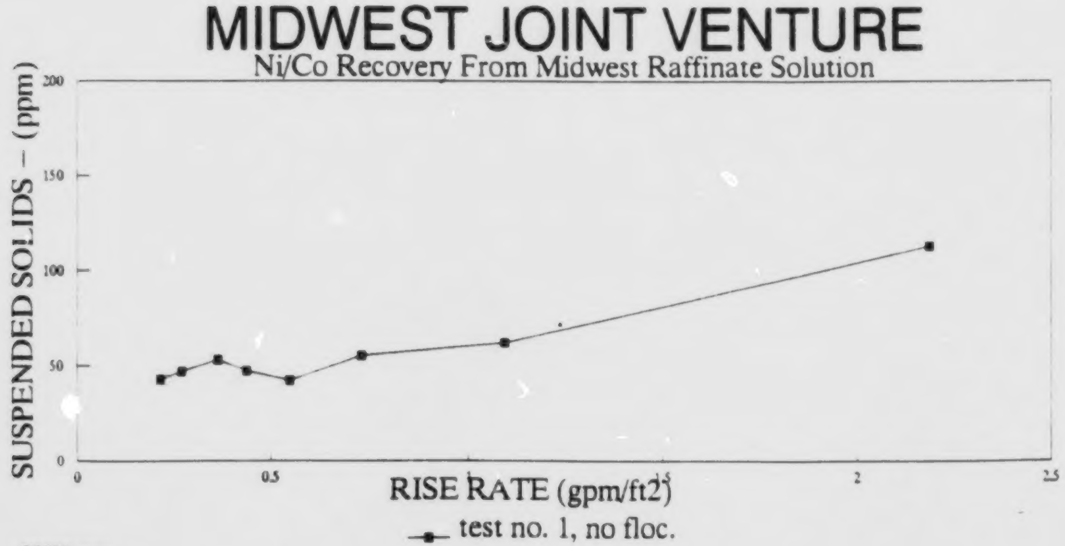
Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION
2nd-STAGE PRECIPITATE CLARIFICATION

CLARIFICATION SCALE-UP FACTOR: 0.7

TEST No. 1 CONDITIONS:

Flocculant -- Percol E-10
Flocculant Dosage - 2mls or 0.5 ppm
Rapid Mix - 10
Floc. Mix - 20

Sample No.	Sample Time (mins.)	Suspended Solids Conc. (ppm)	Rise Rate (gpm/ft2)
E-25	0.0	523	ERR
26	0.5	113	2.2
27	1.0	62	1.1
28	1.5	55	0.7
29	2.0	42	0.5
30	2.5	47	0.4
31	3.0	53	0.4
32	4.0	47	0.3
33	5.0	43	0.2



EIMCO-wws
August 21, 1992

MIDWEST JOINT VENTURE

SASKATOON, SASKATCHEWAN

AUGUST 21, 1992

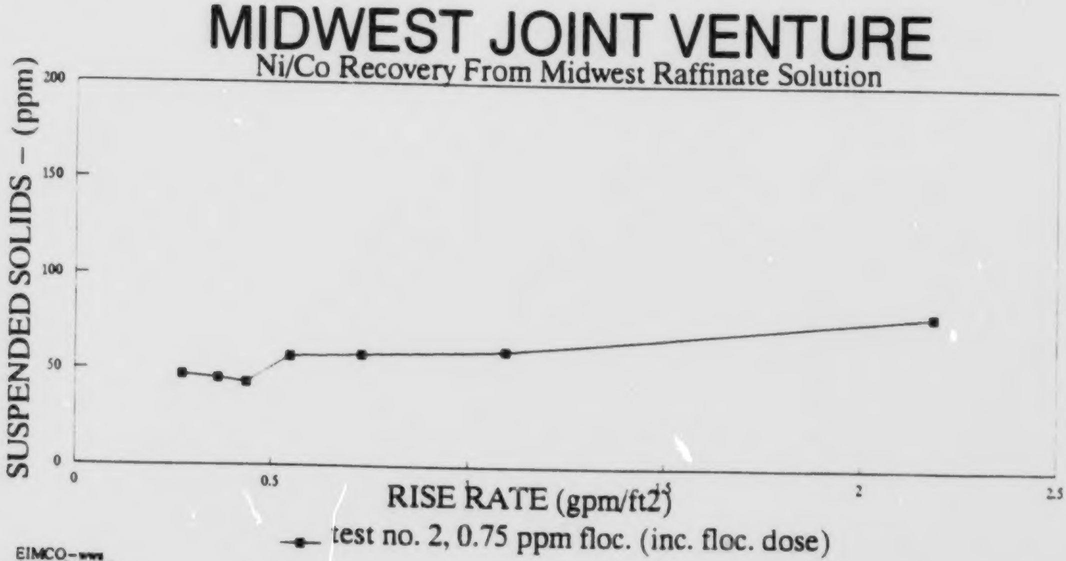
Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION
2nd–STAGE PRECIPITATE CLARIFICATION

CLARIFICATION SCALE–UP
FACTOR: 0.7

TEST No. 2 **CONDITIONS:**

Added Flocculant
Flocculant – Percol E–10
Flocculant Dosage – 3 mls or 0.75 ppm
Rapid Mix – 10 sec.
Floc. Mix – 20 sec.

Sample No.	Sample Time (mins.)	Suspended Solids Conc. (ppm)	Rise Rate (gpm/ft2)
E–34	0.0	533	ERR
35	0.5	80	2.19
36	1.0	60	1.09
37	1.5	58	0.73
38	2.0	57	0.55
39	2.5	43	0.44
40	3.0	45	0.36
41	4.0	47	0.27



MIDWEST JOINT VENTURE

AUGUST 21, 1992

SASKATOON, SASKATCHEWAN

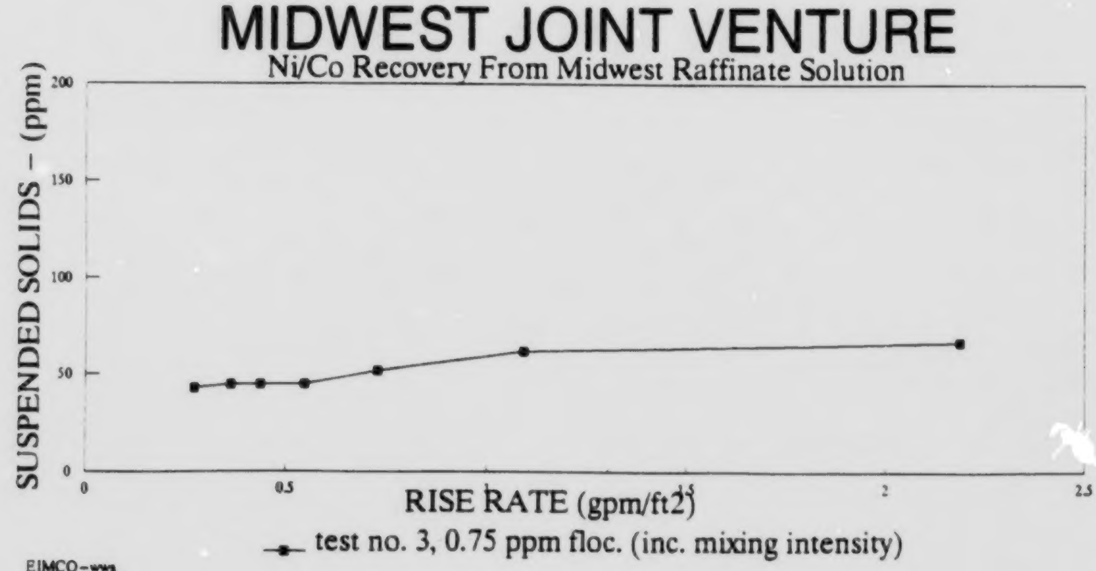
Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION
2nd-STAGE PRECIPITATE CLARIFICATION

CLARIFICATION SCALE-UP
FACTOR: 0.7

TEST No. 3

CONDITIONS: Increased mixing intensity
Flocculant Percol E-10
Flocculant Dosage - 3.0 mls or 0.75 ppm
Rapid Mix - 10 sec.
Floc. Mix - 20 sec. Slow Mix

Sample No.	Sample Time (mins.)	Suspended Solids Conc. (ppm)	Rise Rate (gpm/ft2)
	0.0	533	ERR
42	0.5	67	2.19
43	1.0	62	1.09
44	1.5	52	0.73
45	2.0	45	0.55
46	2.5	45	0.44
47	3.0	45	0.36
48	4.0	43	0.27



EIMCO-wws
August 21, 1992

MIDWEST JOINT VENTURE

SASKATOON, SASKATCHEWAN

AUGUST 21, 1992

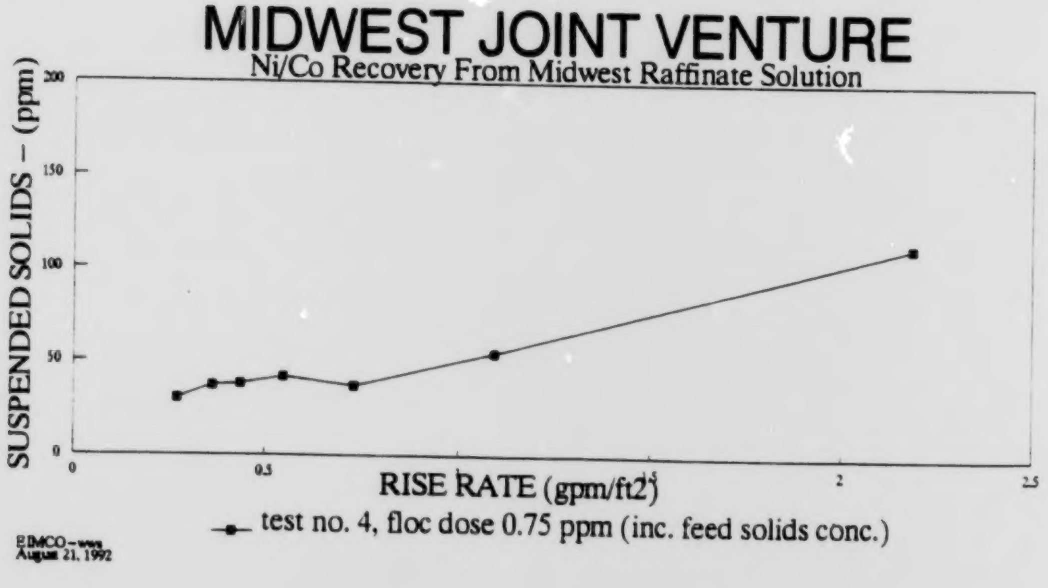
Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION
2nd–STAGE PRECIPITATE CLARIFICATION

CLARIFICATION SCALE–UP FACTOR: 0.7

TEST No. 4 **CONDITIONS:**

Increased feed solids concentration
Flocculant – Percol E–10
Flocculant Dosage – 3 mls or 0.75 ppm
Rapid Mix – 10 sec.
Floc. Mix – 20 sec.

Sample No.	Sample Time (mins.)	Suspended Solids Conc. (ppm)	Rise Rate (gpm/ft2)
49	0.0	1072	ERR
50	0.5	113	2.19
51	1.0	55	1.09
52	1.5	37	0.73
53	2.0	42	0.55
54	2.5	38	0.44
55	3.0	37	0.36
56	4.0	30	0.27



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                         EIMCO PROCESS EQUIPMENT COMPANY
                          THICKENER TEST SUMMARY SHEET

TEST ID: MINATCO/MIDWEST TEST #23                           CREATED: Aug 10, 1992
      2ND. STAGE PRECIPITATE                                UPDATED: Aug 10, 1992

STORAGE FILE: /ROBISON/WORK/MINATCO/MIDWEST23.THK                TIME (MIN)   HEIGHT (ML)
                                                                     0.00        950.
NO FLOCCULANT ADDED                                                   .50        930.
                                                                     1.00        870.
                                                                     1.50        820.
                                                                     2.00        775.
SETTLING VESSEL SIZE (ML/FT):    1445.                               3.00        680.
UNDECANTED SLURRY VOLUME (ML):    954.3                              4.00        600.
           SLURRY WEIGHT (G):    1613.90   TARE (G):  648.00         5.00        550.
DECANTED SLURRY VOLUME (ML):      240.4                              7.00        480.
         SLURRY WEIGHT (G):       900.00                            11.00        470.
DRY SOLIDS WEIGHT (G):            148.60   TARE (G):  127.40        14.00        390.
ULTIMATE INTERFACE HEIGHT (ML)    235.                              18.00        360.
                                                                   101.00        270.
SPECIFIC GRAVITY SUPERNATANT        1.0000                         179.00        250.
SPECIFIC GRAVITY SOLIDS             2.1992                         330.00        235.
                                                                  *******     *******
                                                                  *******     *******
UNDERFLOW CONCENTRATION     WEIGHT % SOLIDS      CU (MT/CU.M)     *******     *******
    INITIAL                      2.19              .02221         *******     *******
    MINIMUM DESIRED              2.20              .02222         *******     *******
    FINAL (TEST)                 8.56              .08980         *******     *******
    ULTIMATE                     8.56              .08980         *******     *******
                                                                  *******     *******
                                                                  *******     *******
   UNDERFLOW          UNDERFLOW           UNIT AREA        UNIT AREA          *******     *******
 WEIGHT % SOLIDS     CU (MT/CU.M)        SQ.M/MTPD    SQ.M/MTPD CORRECTED     *******     *******
                                                                              *******     *******
      8.6              .08980             51.664           6.189              *******     *******
      8.0              .08365             26.447           3.699              *******     *******
      7.0              .07278              9.407           2.162              *******     *******
      6.0              .06203              3.419           1.370              *******     *******
      5.0              .05140              1.543           1.140              *******     *******
      4.0              .04089               .964            .845              *******     *******
      3.0              .03050               .409            .362              *******     *******
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Figure ___ BATCH INTERFACE SETTLING DATA
MINATCO/MIDWEST TEST #23
2ND. STAGE PRECIPITATE

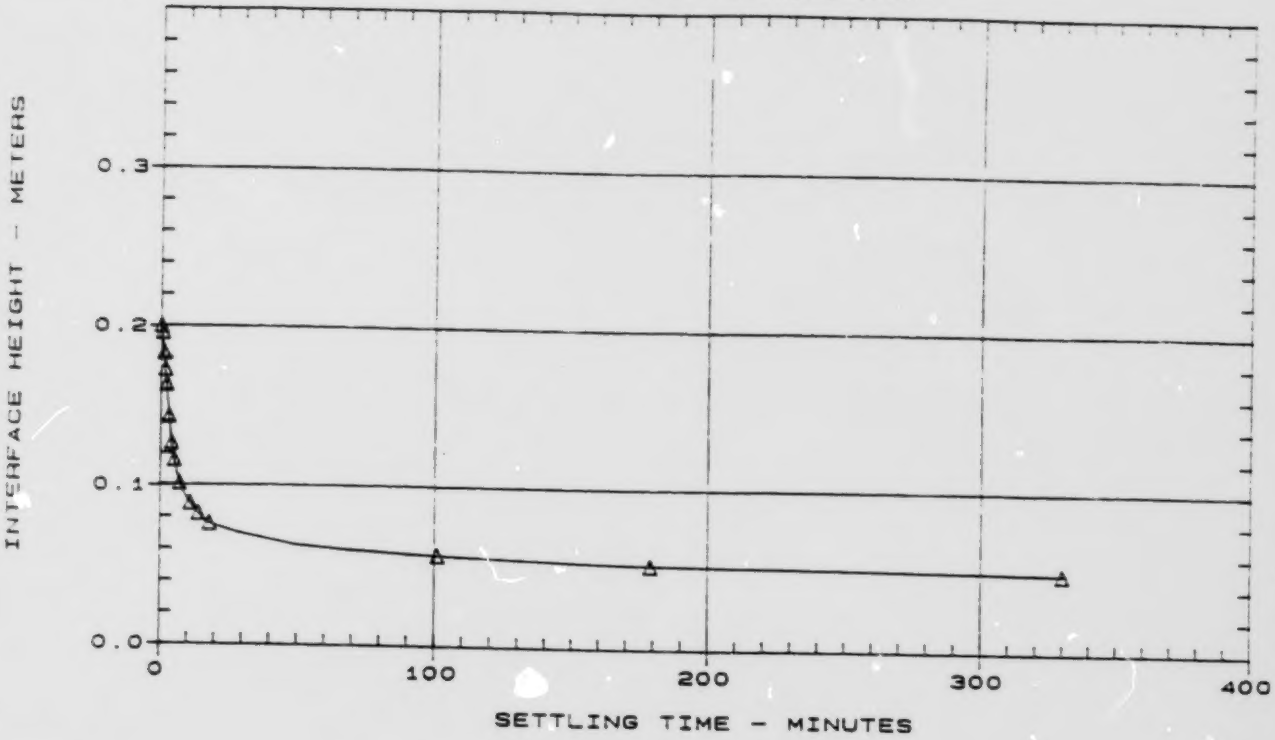
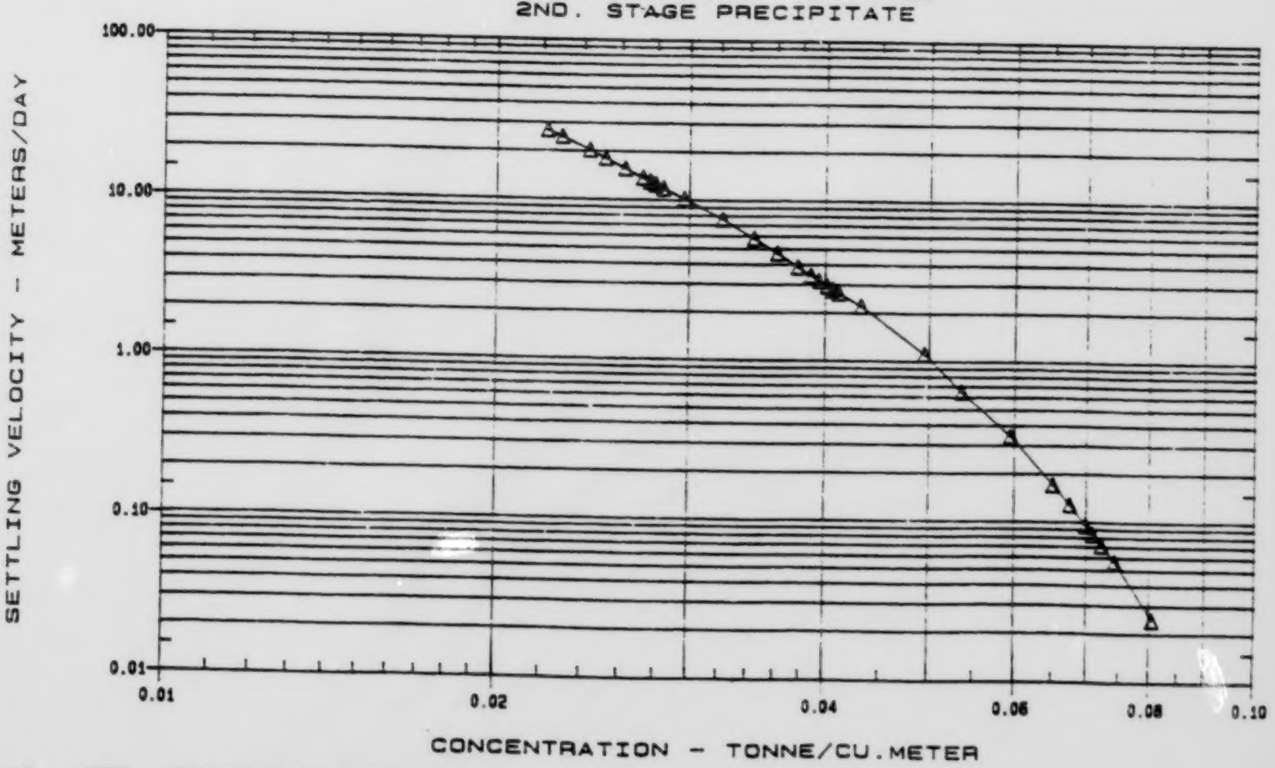


Figure ___ SETTLING VEL vs CONCENTRATION
MINATCO/MIDWEST TEST #23
2ND. STAGE PRECIPITATE



Aug 10, 1992 MINATCO/MIDWEST23

Figure __ UNIT AREA vs UF CONCENTRATION
MINATCO/MIDWEST TEST #23
2ND. STAGE PRECIPITATE

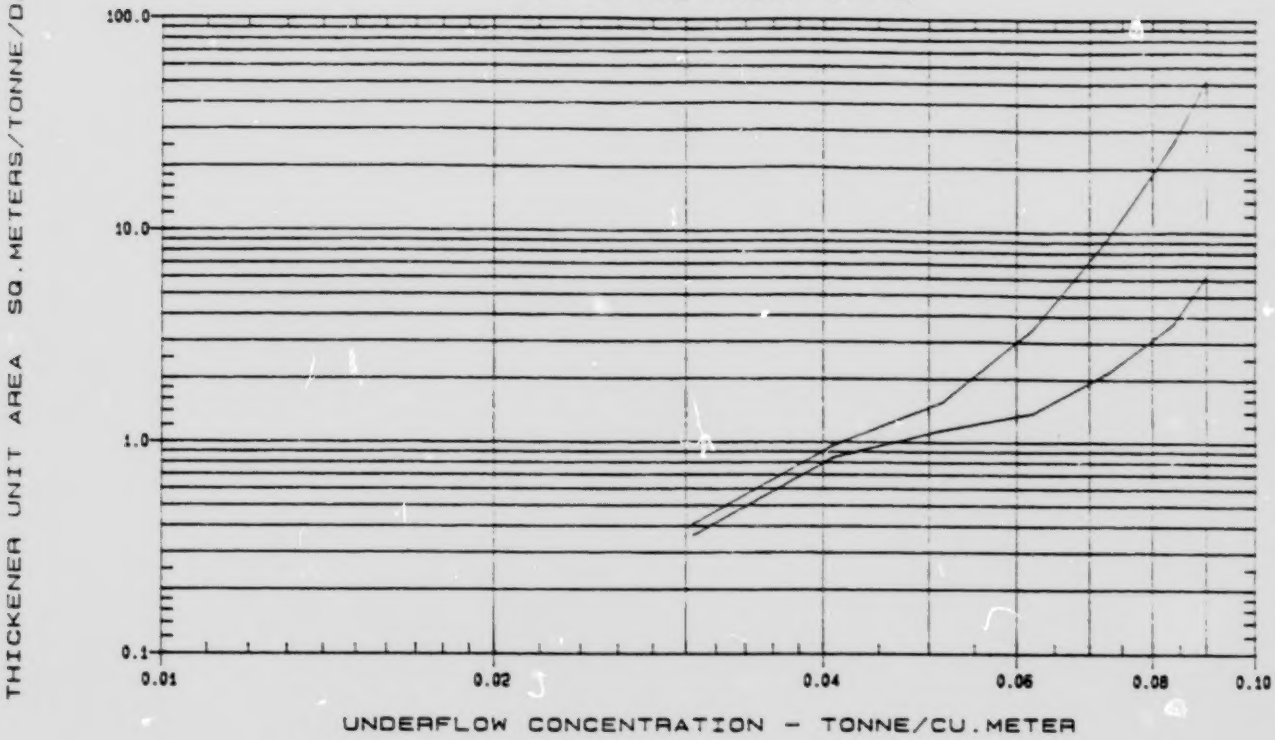
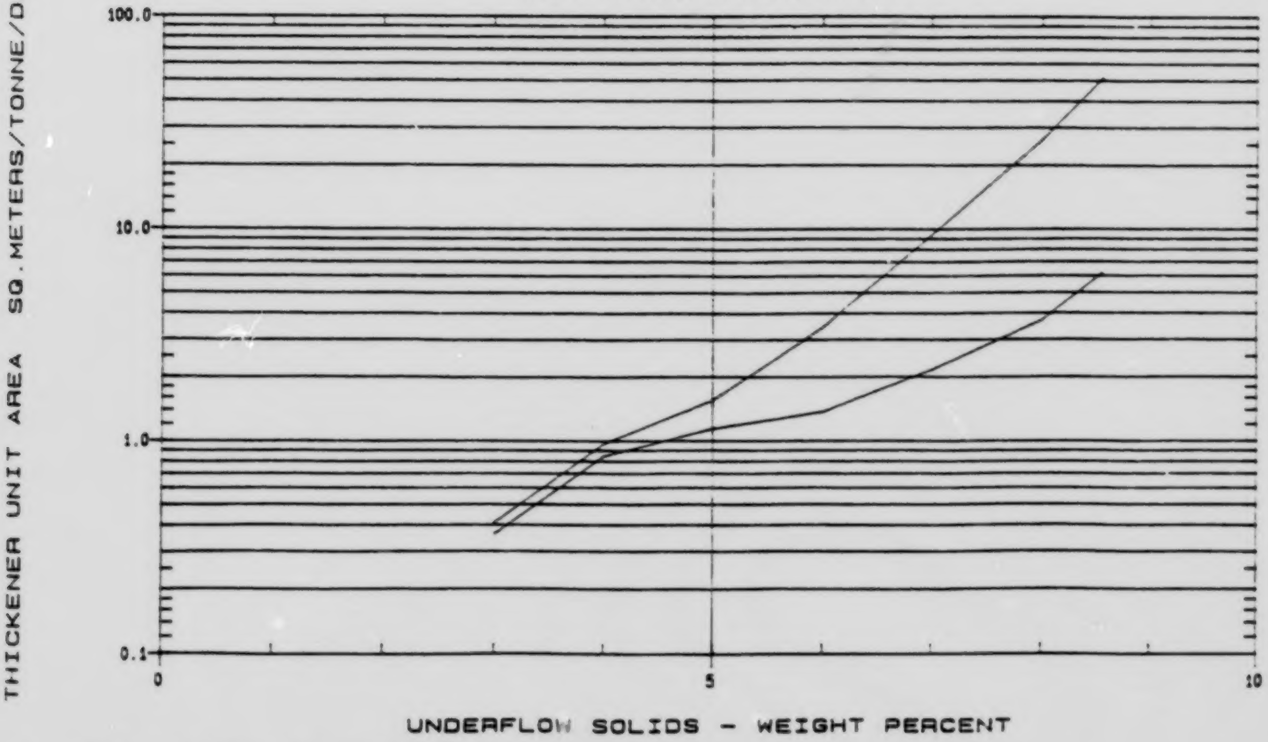


Figure __ UNIT AREA vs PCT. UF SOLIDS
MINATCO/MIDWEST TEST #23
2ND. STAGE PRECIPITATE



Aug 10. 1992 MINATCO/MIDWEST23

SECTION 3.0

Ni/Co PRECIPITATE THICKENING and CLARIFICATION

DISCUSSION AND CONCLUSIONS

SECTION 3.0 - DISCUSSION & CONCLUSIONS

D) Ni/Co Precipitate Thickening and Clarification

Three (3) standard bench-scale standard thickening tests and two (2) clarification tests were conducted on the sample of nickel/cobalt precipitate slurry.

The data from this testing was correlated for the thickener sizing. Attached is the result of the thickening and clarification test work along with the various graphs.
The following is a review of some of the design parameters of the thickener.

Flocculant Type and Dosage

In this thickening and clarification test work Allied Colloid's Percol E-10 was used. One of the thickening tests was run without flocculant, the remaining thickening and clarification tests included flocculant addition. The higher levels of flocculant addition in the thickening tests did not reduce the design unit area nor increase the underflow solids concentration. From the work conducted we would expect the flocculant dosage to be in the 0.5-1.0 mg/L range.

Slurry Flocculant Mixing Intensity

Adding flocculant to the feed slurry and the appropriate mixing of this slurry is of course important to obtain effective flocculation. In the clarification testing we applied a flash mix for approximately 10 seconds and a floc mix for 20 seconds. Consideration should be given to the EIMCO Reactor-Clarifier to provide the type of flocculant and slurry mixing to minimize the suspended solids reporting to overflow. We reported sizing based upon a clarifier overflow containing less than 100 mg/L suspended solids. While the clarifier design should use this overflow solids loading we would expect that the overflow quality, using a Reactor-Clarifier will be in the 50 mg/L range.

SECTION 3.0 - DISCUSSION & CONCLUSIONS

D) Ni/Co Precipitate Thickening and Clarification

Thickener Underflow Solids Concentration

The thickening tests produced an underflow solids concentration in the 7 wt% range. It is expected that the solids will densify to at least 15 weight percent range. In this testing the thickening tests were run at a feed solids concentration of only approximately 1 wt% solids and accordingly there is not much solids in the cylinder and full thickening can not be reached. An increase in the sludge depth will improve thickening and increase the final solids concentration. The final sludge from this clarifier will be used as feed to the Shriver Pressure filter. Lab pressure filter tests were carried out on a sample of Ni/Co slurry prepared from the same precipitate sample. The solids actually thickened to approximately 16 wt% solids. In addition, other thickening work by EIMCO on a nickel carbonate precipitate gave thickened solids in the 15 wt% range. It will be important to produce as high an underflow solids concentration as possible since this thickened sludge reports to the pressure filter and will reduce the hydraulic loading on the filter.

Feed Solids Concentration

The slurry was tested at the feed solids concentration ranging from 0.5 to approximately 1 wt% in the thickening and clarification test work. In actual fact the clarifier will be operating at a feed solids concentration of 0.1 to 0.2 wt%. At this low solids concentration it may be necessary to recirculate solids in order to maximize flocculation and minimize the suspended solids reporting to overflow. The feed solids concentration can be increased through external sludge recirculation or by using the EIMCO Reactor clarifier. This clarifier design provides both flocculant/slurry mixing and internal sludge recirculation.

SECTION 3.0 - DISCUSSION & CONCLUSIONS

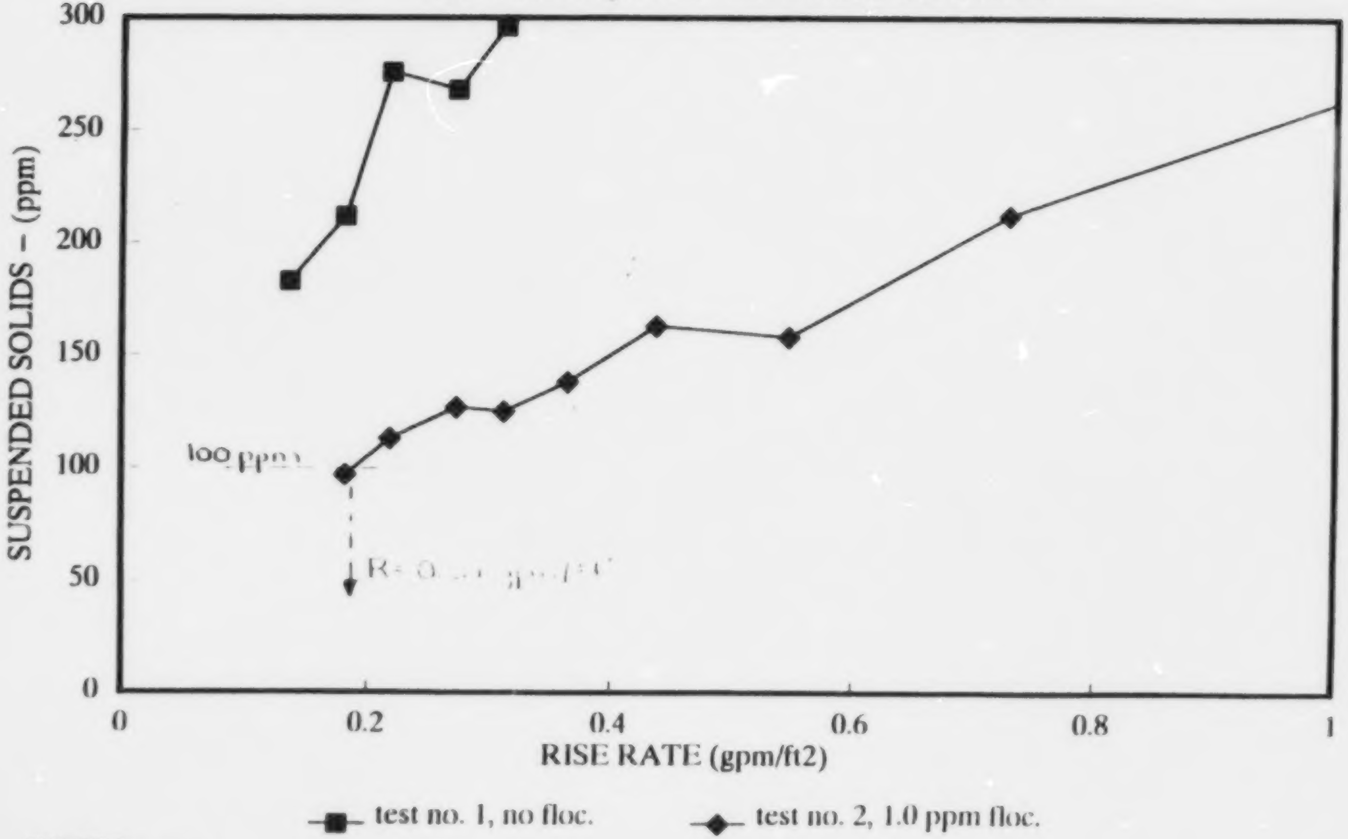
D) Ni/Co Precipitate Thickening and Clarification

Clarifier Sizing

The nickel/cobalt EIMCO Reactor-Clarifier should be sized based upon a design rise rate of 7 L/min/m^2. At a clarifier feed rate of 55 m^3/h a 12802 mm diameter clarifier is required. The clarifier is sized to produce an overflow clarity of 50-100 ppm suspended solids and an underflow solids concentration of 15 weight percent solids.

MIDWEST JOINT VENTURE

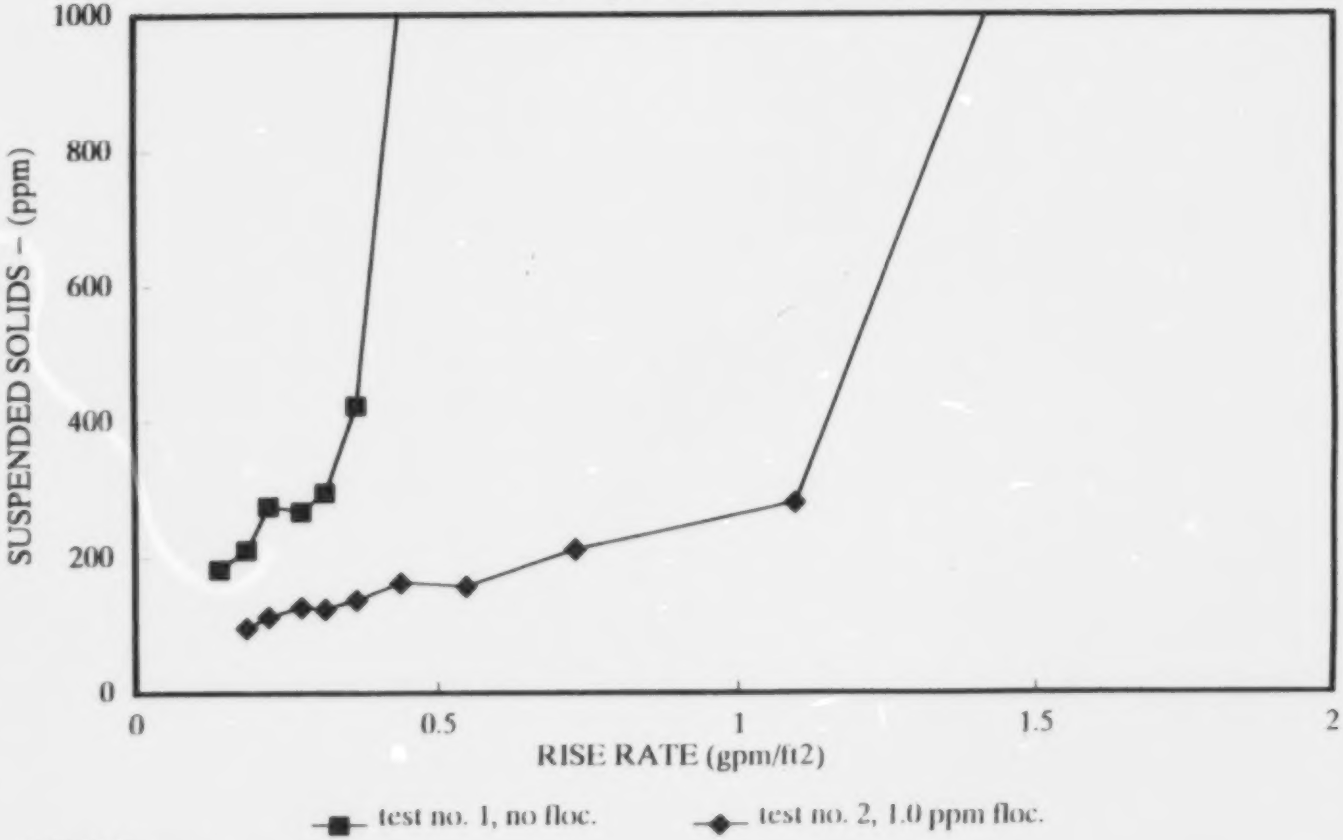
Ni/Co Recovery From Midwest Raffinate Solution



EIMCO–wws
July 22. 1992

MIDWEST JOINT VENTURE

Ni/Co Recovery From Midwest Raffinate Solution



EIMCO–wws
July 22. 1992

MIDWEST JOINT VENTURE

AUGUST 21, 1992

SASKATOON, SASKATCHEWAN

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

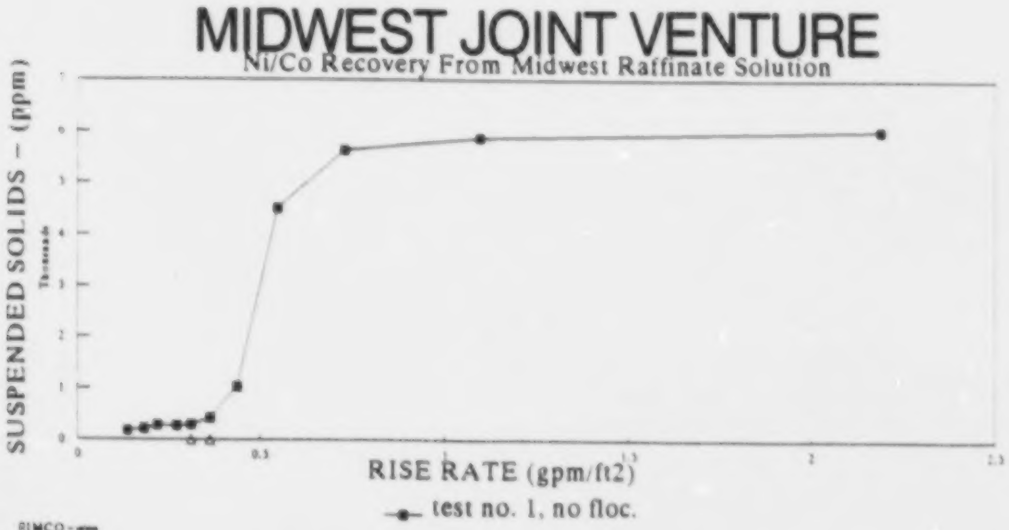
Ni/Co PRECIPITATE CLARIFICATION/THICKENING

CLARIFICATION SCALE-UP FACTOR: 0.7

TEST No. 1 **CONDITIONS:**

Flocculant
Flocculant Dosage - None
Rapid Mix - N/A
Floc. Mix - N/A

Sample No.	Sample Time (mins.)	Suspended Solids Conc. (ppm)	Rise Rate (gpm/ft2)
1	0.0	6090	ERR
2	0.5	6015	2.19
3	1.0	5870	1.09
4	1.5	5620	0.73
5	2.0	4490	0.55
6	2.5	1025	0.44
7	3.0	424	0.36
8	3.5	296	0.31
9	4.0	268	0.27
10	5.0	276	0.22
11	6.0	212	0.18
12	8.0	183	0.14



RIMCO - wws
July 22, 1992

MIDWEST JOINT VENTURE

AUGUST 21, 1992

SASKATOON, SASKATCHEWAN

Ni/Co RECOVERY FROM MIDWEST RAFFINATE SOLUTION

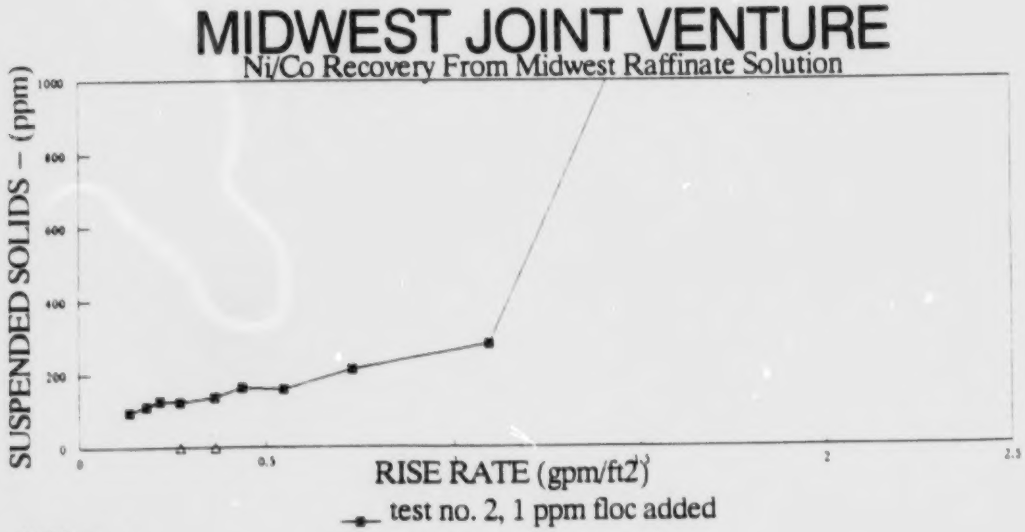
Ni/Co PRECIPITATE CLARIFICATION/THICKENING

CLARIFICATION SCALE-UP FACTOR: 0.7

TEST No. 2 **CONDITIONS:**

Added Flocculant
Flocculant - Percol E-10
Flocculant Dosage - 4 mls or 1.0 ppm
Rapid Mix
Floc. Mix

Sample No.	Sample Time (mins.)	Suspended Solids Conc. (ppm)	Rise Rate (gpm/ft2)
14	0.0	5730	ERR
15	0.5	2740	2.19
16	1.0	280	1.09
17	1.5	212	0.73
18	2.0	158	0.55
19	2.5	163	0.44
20	3.0	138	0.36
21	4.0	125	0.27
22	5.0	127	0.22
23	6.0	113.0	0.18
24	8.0	97.0	0.14
25	10.0	523.0	0.11



EIMCO - wws
July 22, 1992

MIDWEST JOINT VENTURE

(DENISON MINES LIMITED - OPERATOR)

Ni/Co PRECIPITATE SLURRY THICKENING SUMMARY

Test No.	Feed Solids Conc. (wt%)	Polymer Dosage (gms/tds)	Final Solids Conc. (wt%)	Design Unit Area m^2/mtpd @ u/f density 7 wt%	Test Conditions
1C	0.7	None	7.1	8	No Floc Added
2C	0.8	64.1	7.1	4	Floc Percol Added
3C	0.8	134.7	6.8	4	Increased Floc Doseage
4C	0.72	208	6.4	4	Slurry Mix Intensity

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                          EIMCO PROCESS EQUIPMENT COMPANY
                           THICKENER TEST SUMMARY SHEET

TEST ID: Minatco/Midwest #9                                  CREATED: Jul 31. 1992
         Nickel/Cobalt Precipitate                           UPDATED: Aug  4. 1992

STORAGE FILE: /ROBISON/WORK/MINATCO/MINATCO1.THK              TIME (MIN)   HEIGHT (ML)
                                                                  0.00         1995.
NO FLOCCULANT ADDED                                                .50         1940.
                                                                  1.00         1900.
                                                                  2.00         1790.
                                                                  4.00         1530.
SETTLING VESSEL SIZE (ML/FT):     1445.                           5.00         1410.
UNDECANTED SLURRY VOLUME (ML):    1972.8                          7.00         1170.
           SLURRY WEIGHT (G):     2886.20   TARE (G):  902.60     9.00          930.
DECANTED SLURRY VOLUME (ML):       100.5                         11.00          775.
         SLURRY WEIGHT (G):       1101.90                        13.00          680.
DRY SOLIDS WEIGHT (G):             190.50   TARE (G):  175.50    15.00          610.
ULTIMATE INTERFACE HEIGHT (ML)    200.                           17.00          555.
                                                                 24.00          460.
SPECIFIC GRAVITY SUPERNATANT        1.0000                       30.00          420.
SPECIFIC GRAVITY SOLIDS             3.5997                       35.00          395.
                                                                 51.00          340.
                                                                 68.00          300.
UNDERFLOW CONCENTRATION     WEIGHT % SOLIDS        CU (MT/CU.M)   86.00          280.
    INITIAL                       .76               .00760      116.00          250.
   MINIMUM DESIRED                .76               .00760      *******       *******
   FINAL (TEST)                  5.80               .06068      *******       *******
   ULTIMATE                      7.19               .07584      *******       *******
                                                                *******       *******
                                                                *******       *******
   UNDERFLOW           UNDERFLOW         UNIT AREA        UNIT AREA           *******       *******
 WEIGHT % SOLIDS     CU (MT/CU.M)       SQ.M/MTPD    SQ.M/MTPD CORRECTED      *******       *******
                                                                *******       *******
     5.8               .06068            27.363           6.235       *******       *******
     5.0               .05187            16.185           4.216       *******       *******
     4.0               .04119             8.845           3.840       *******       *******
     3.0               .03066             4.781           3.647       *******       *******
     2.0               .02029             1.895           1.699       *******       *******
     1.0               .01007              .394            .356       *******       *******
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Figure ___ BATCH INTERFACE SETTLING DATA
Minatco/Midwest #9
Nickel/Cobalt Precipitate

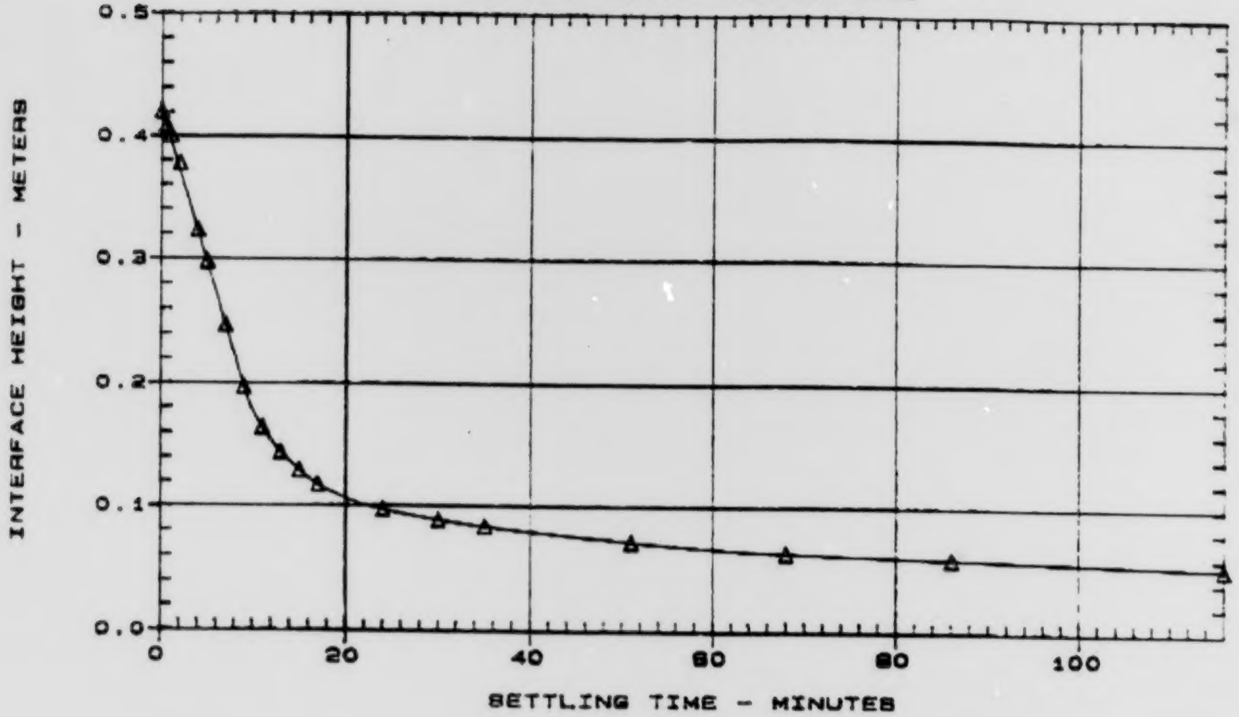
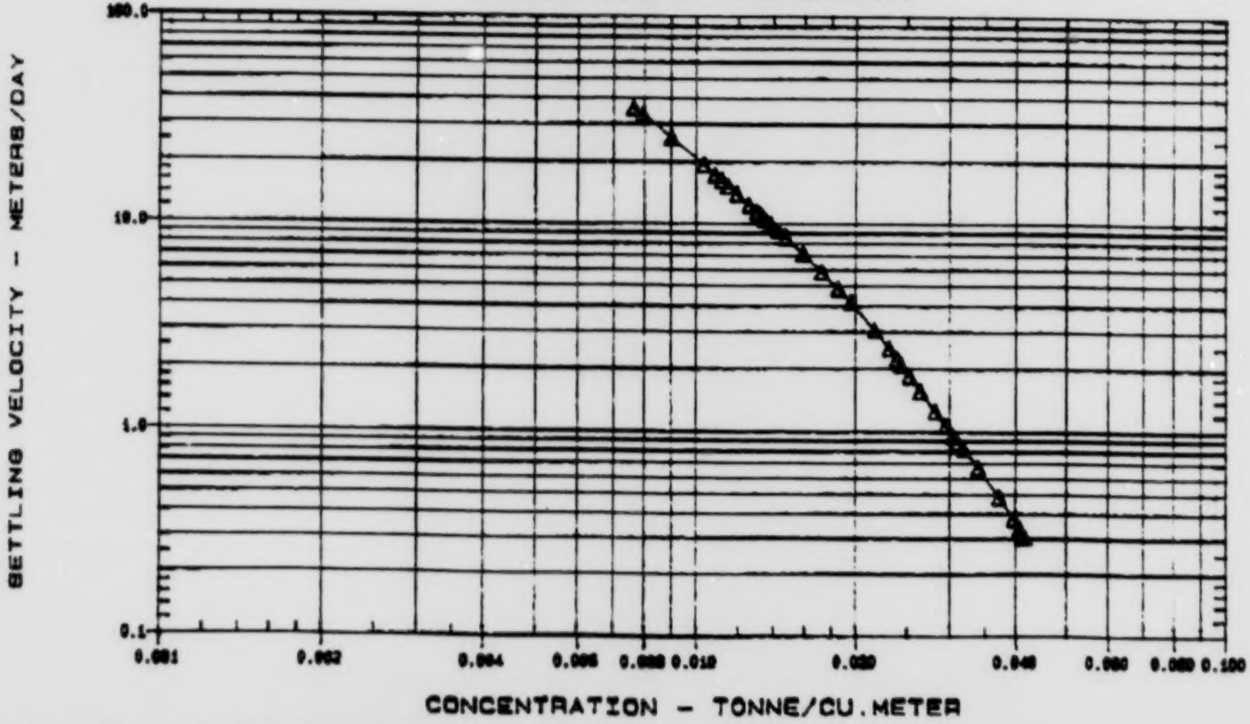


Figure ___ SETTLING VEL vs CONCENTRATION
Minatco/Midwest #9
Nickel/Cobalt Precipitate



AUG 4, 1992 MINATCO/MINATCO1

Figure ___ UNIT AREA vs UF CONCENTRATION
Minatco/Midwest #9
Nickel/Cobalt Precipitate

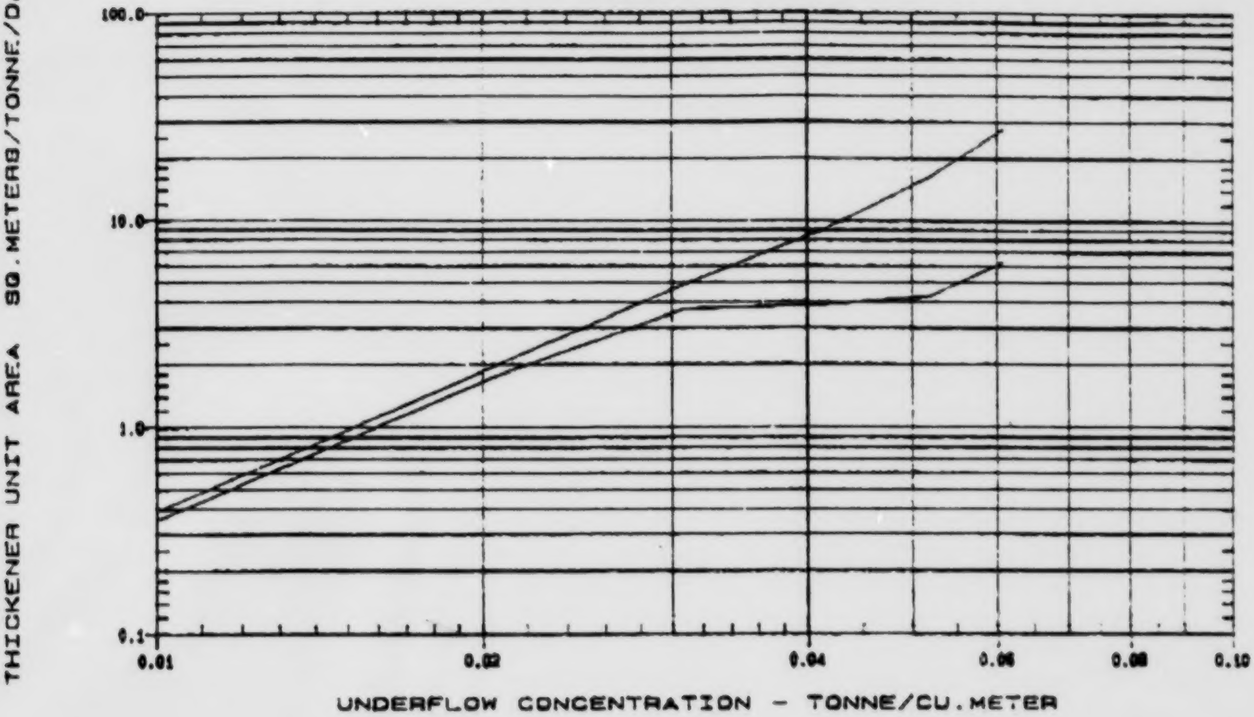
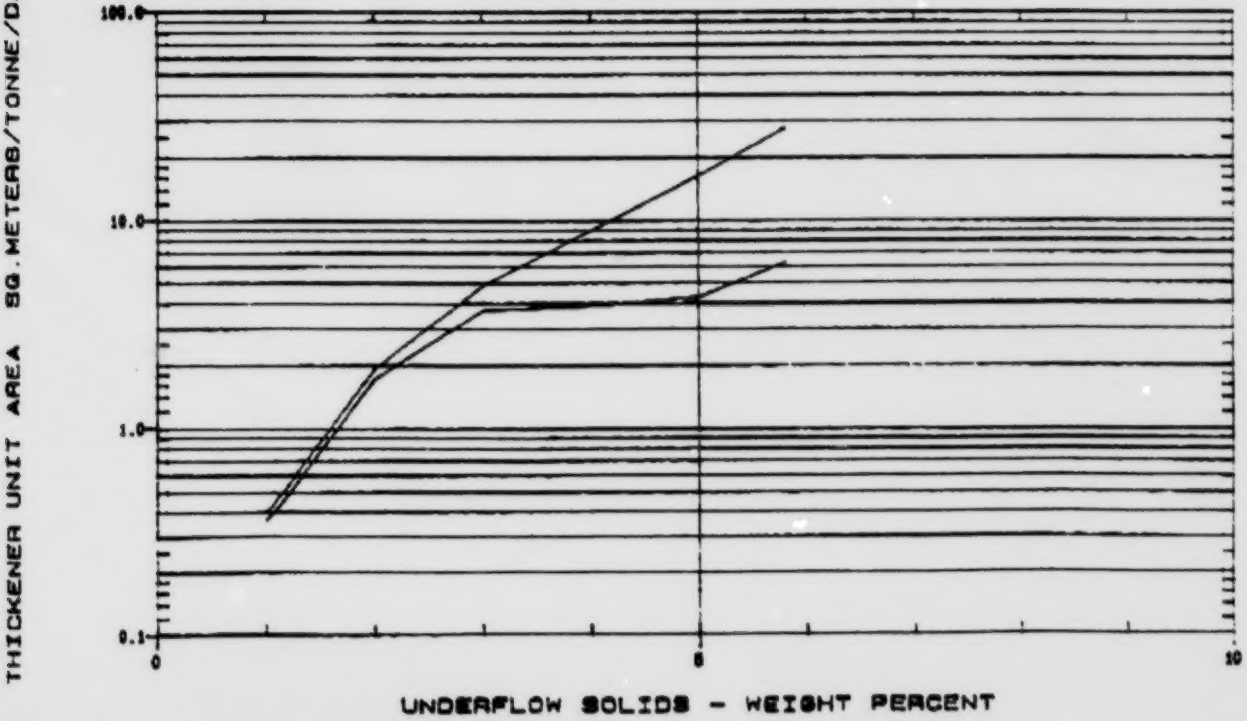


Figure ___ UNIT AREA vs PCT. UF SOLIDS
Minatco/Midwest #9
Nickel/Cobalt Precipitate



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                              EIMCO PROCESS EQUIPMENT COMPANY
                               THICKENER TEST SUMMARY SHEET

TEST ID: Minatco/Midwest 010                                          CREATED: Jul 31. 1992
         Nickel/Cobalt Precipitate                                    UPDATED: Aug  4. 1992

STORAGE FILE: /ROBISON/WORK/MINATCO/MINATCO10.THK                           TIME (MIN)   HEIGHT (ML)
                                                                               0.00        1995.
FLOCCULANT: Percol E-10                 CONCENTRATION (G/L):    1.00           1.00        1890.
                                        VOLUME ADDED (ML):      1.0            2.00        1720.
                                        DOSAGE:                64.1  G/MT      3.00        1520.
                                                                               5.00        1090.
SETTLING VESSEL SIZE (ML/FT):    1461.                                         6.00         880.
UNDECANTED SLURRY VOLUME (ML):   1978.4                                        8.00         695.
           SLURRY WEIGHT (G):    2887.20     TARE (G):  897.50                11.00         580.
DECANTED SLURRY VOLUME (ML):      196.2                                       14.00         525.
         SLURRY WEIGHT (G):      1109.00                                      17.00         485.
DRY SOLIDS WEIGHT (G):            145.00     TARE (G):  130.20                20.00         455.
ULTIMATE INTERFACE HEIGHT (ML)   210.                                         27.00         405.
                                                                              30.00         385.
SPECIFIC GRAVITY SUPERNATANT        1.0000                                    37.00         355.
SPECIFIC GRAVITY SOLIDS             3.6001                                    54.00         300.
                                                                              72.00         270.
                                                                             102.00         250.
UNDERFLOW CONCENTRATION      WEIGHT % SOLIDS         CU (MT/CU.M)            *******     *******
     INITIAL                       .78                 .00789                *******     *******
     MINIMUM DESIRED               .78                 .00789                *******     *******
     FINAL (TEST)                 6.01                 .06292                *******     *******
     ULTIMATE                     7.10                 .07491                *******     *******
                                                                             *******     *******
                                                                             *******     *******
   UNDERFLOW            UNDERFLOW          UNIT AREA          UNIT AREA      *******     *******
WEIGHT % SOLIDS       CU (MT/CU.M)        SQ.M/MTPD    SQ.M/MTPD CORRECTED   *******     *******
                                                                             *******     *******
      6.0                .06292             21.585            3.619          *******     *******
      6.0                .06272             21.289            3.600          *******     *******
      5.0                .05187             10.986            3.356          *******     *******
      4.0                .04119              6.779            2.995          *******     *******
      3.0                .03066              3.578            2.436          *******     *******
      2.0                .02029              1.464            1.315          *******     *******
      1.0                .01007               .321             .700          *******     *******
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Figure __ BATCH INTERFACE SETTLING DATA
Minatco/Midwest #10
Nickel/Cobalt Precipitate

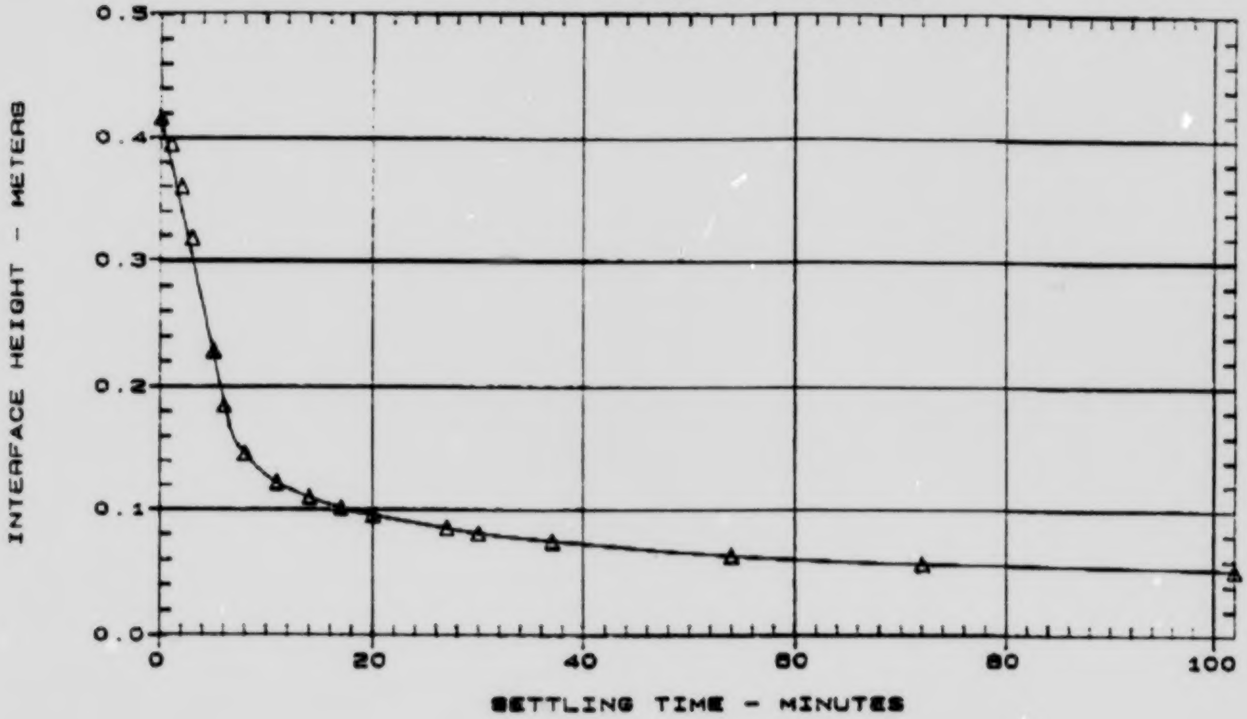
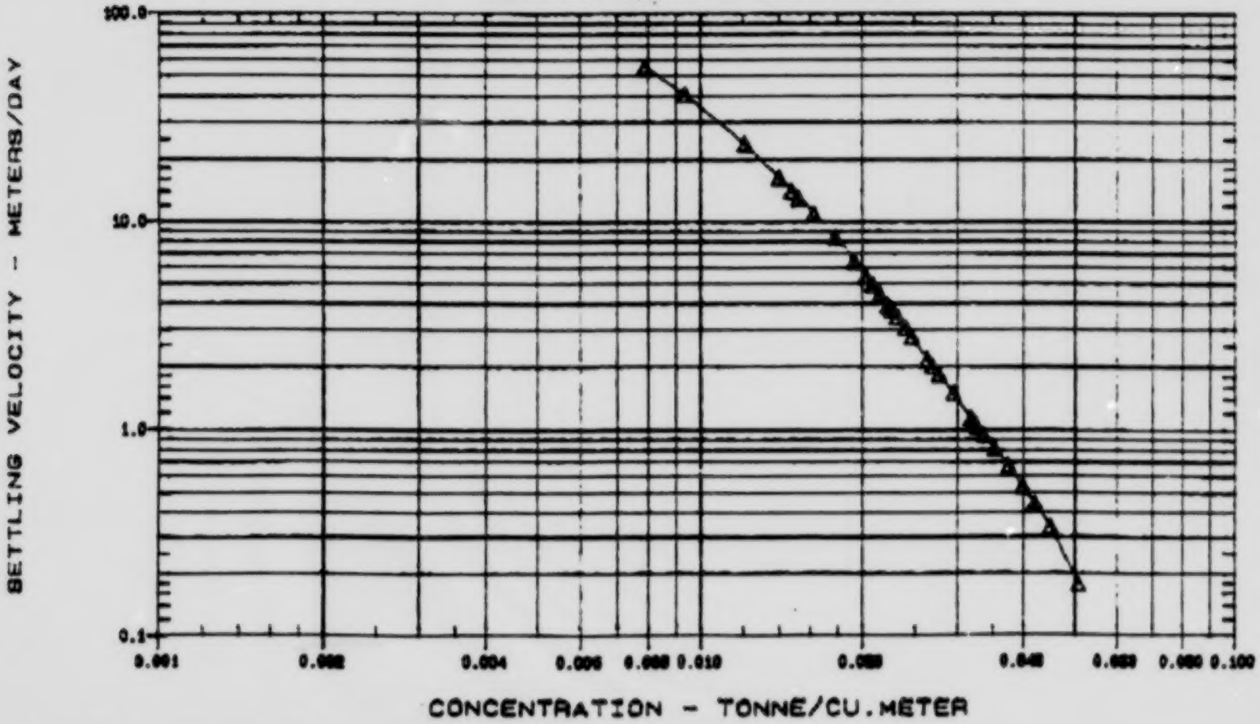


Figure __ SETTLING VEL vs CONCENTRATION
Minatco/Midwest #10
Nickel/Cobalt Precipitate



AUG 4, 1992 MINATCO/MINATCO10

Figure ___ UNIT AREA vs UF CONCENTRATION
Minatco/Midwest #10
Nickel/Cobalt Precipitate

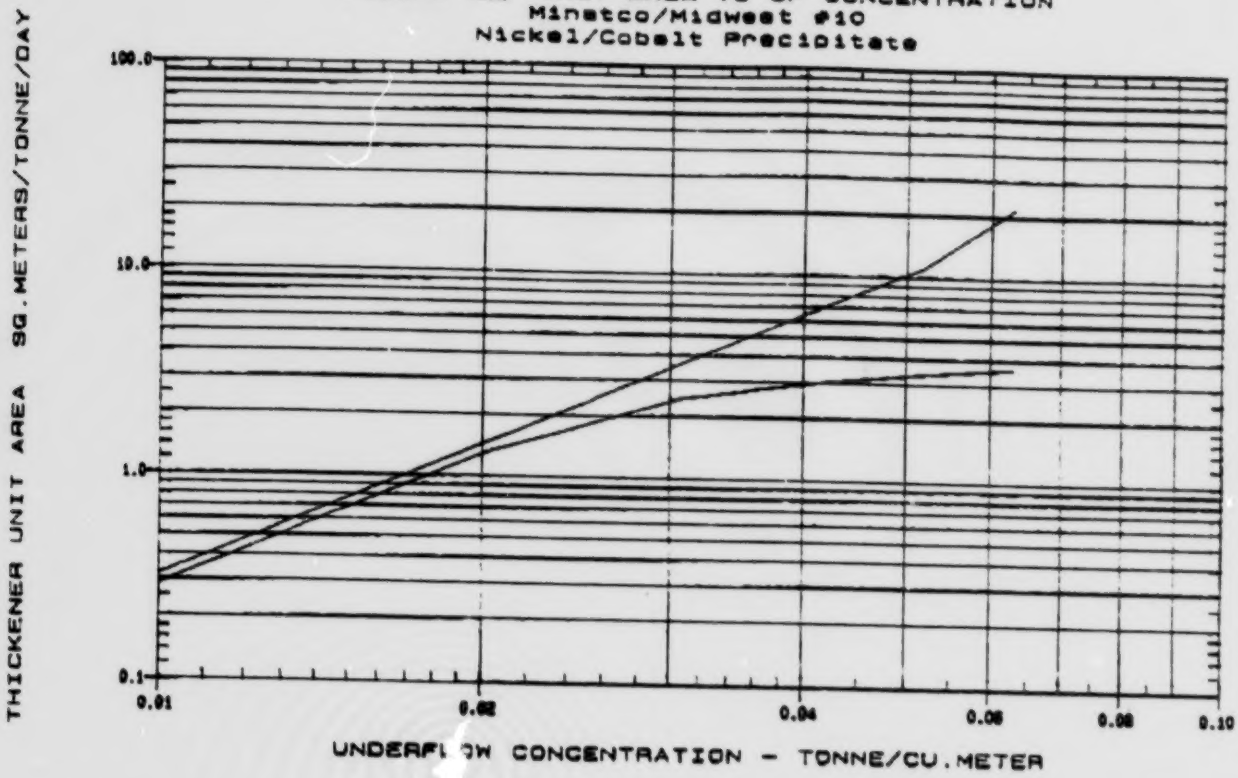
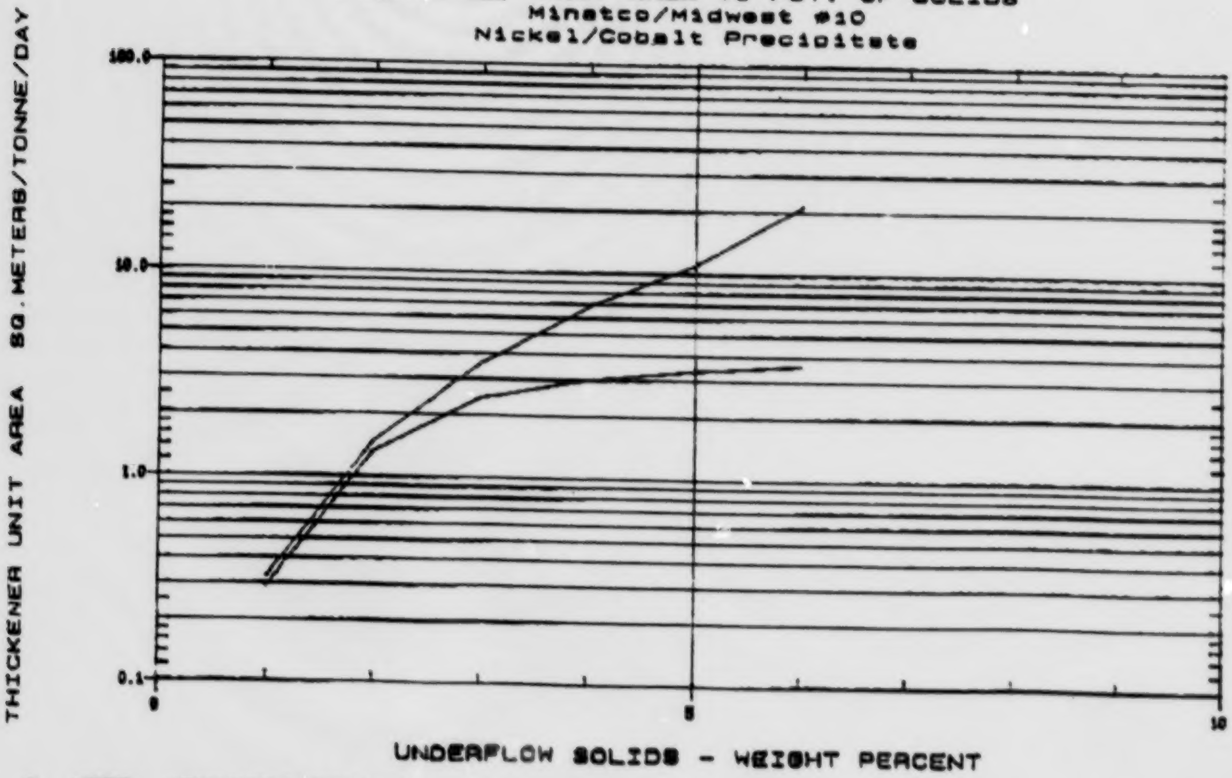


Figure ___ UNIT AREA vs PCT. UF SOLIDS
Minatco/Midwest #10
Nickel/Cobalt Precipitate



AUG 4, 1992 MINATCO/MINATCO10

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                    EIMCO PROCESS EQUIPMENT COMPANY
                     THICKENER TEST SUMMARY SHEET

TEST ID: Minatco/Midwest                                   CREATED: Jul 31, 1992
         Nickel/Cobalt Precipitate                         UPDATED: Aug 25, 1992

STORAGE FILE: /ROBINSON/WORK/MINATCO/MINATCO11.THK          TIME (MIN)   HEIGHT (ML)
                                                               0.00         1895.
FLOCCULANT: Percol E-10             CONCENTRATION (G/L):   1.00        1.00         1750.
                                    VOLUME ADDED (ML):     2.0         1.50         1570.
                                    DOSAGE:            134.2  G/MT     2.00         1370.
                                                                       3.00          950.
SETTLING VESSEL SIZE (ML/FT):   1532.                                  4.00          730.
UNDECANTED SLURRY VOLUME (ML):  1902.5                                 5.00          645.
           SLURRY WEIGHT (G):   3807.90   TARE (G): 1894.60            6.00          595.
DECANTED SLURRY VOLUME (ML):     193.6                                 8.00          530.
         SLURRY WEIGHT (G):     1298.00                               10.00          480.
DRY SOLIDS WEIGHT (G):           134.90   TARE (G):  120.00           13.00          420.
ULTIMATE INTERFACE HEIGHT (ML)   200.                                 16.00          390.
                                                                      23.00          320.
SPECIFIC GRAVITY SUPERNATANT       1.0000                             32.00          285.
SPECIFIC GRAVITY SOLIDS            3.5953                             40.00          260.
                                                                      60.00          250.
                                                                      90.00          235.
UNDERFLOW CONCENTRATION    WEIGHT % SOLIDS        CU (MT/CU.M)      *******      *******
    INITIAL                      .75                .00752          *******      *******
    MINIMUM DESIRED              .75                .00752          *******      *******
    FINAL (TEST)                5.80                .06061          *******      *******
    ULTIMATE                    6.79                .07121          *******      *******
                                                                    *******      *******
                                                                    *******      *******
    UNDERFLOW           UNDERFLOW          UNIT AREA        UNIT AREA               *******      *******
  WEIGHT % SOLIDS      CU (MT/CU.M)        SQ.M/MTPD    SQ.M/MTPD CORRECTED         *******      *******
                                                                                    *******      *******
        5.8              .06061             22.058           2.896                  *******      *******
        5.0              .05187              9.000           2.328                  *******      *******
        4.0              .04119              4.622           2.099                  *******      *******
        3.0              .03066              2.291           1.853                  *******      *******
        2.0              .02029              1.225           1.026                  *******      *******
        1.0              .01007               .303            .221                  *******      *******
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Figure — BATCH INTERFACE SETTLING DATA
Minatco/Midwest
Nickel/Cobalt Precipitate

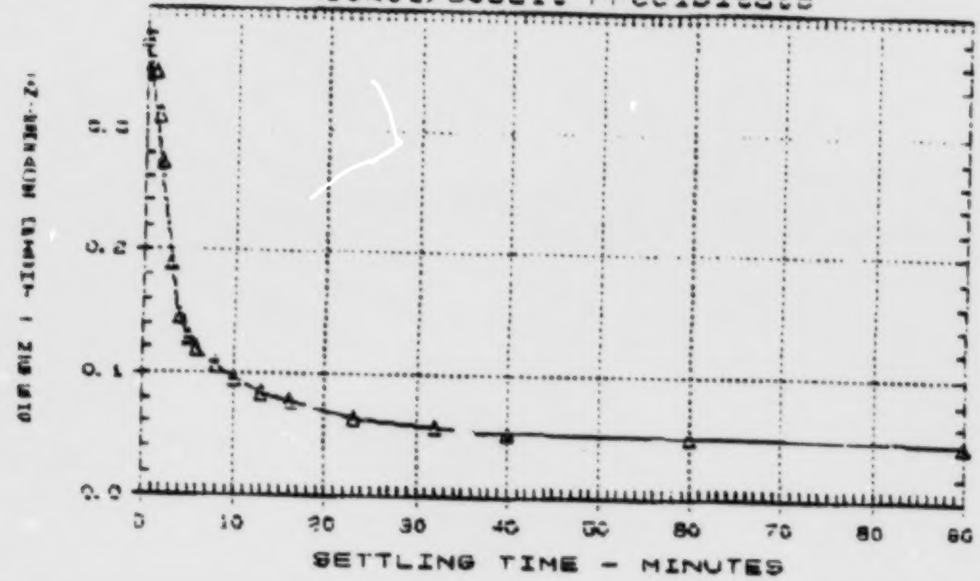
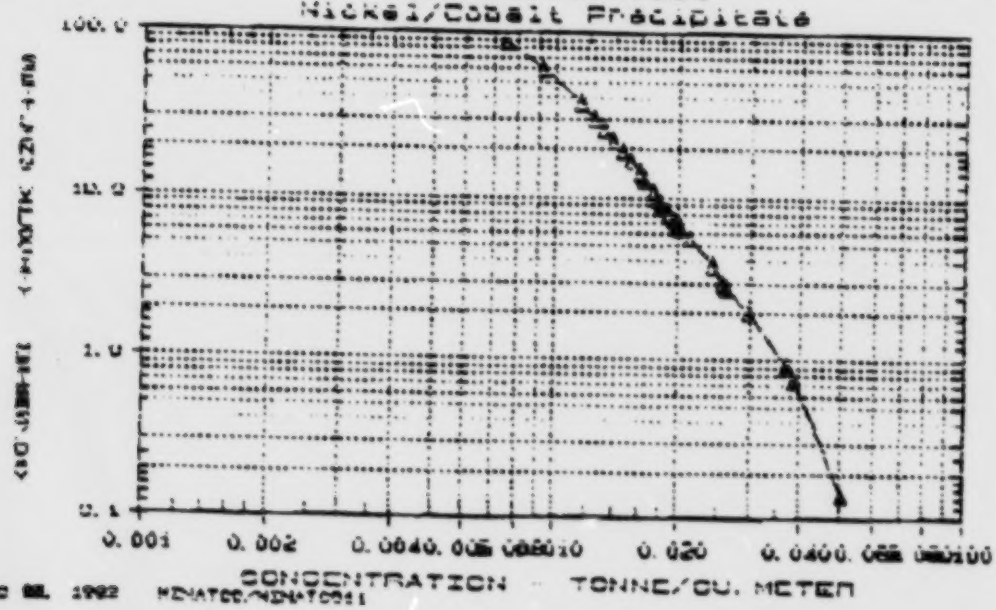


Figure — SETTLING VEL VS CONCENTRATION
Minatco/Midwest
Nickel/Cobalt Precipitate



AUG 08. 1992 MINATCO/MINATCO11

Figure UNIT AREA vs UF CONCENTRATION
Minatco/Midwest
Nickel/Cobalt Precipitate

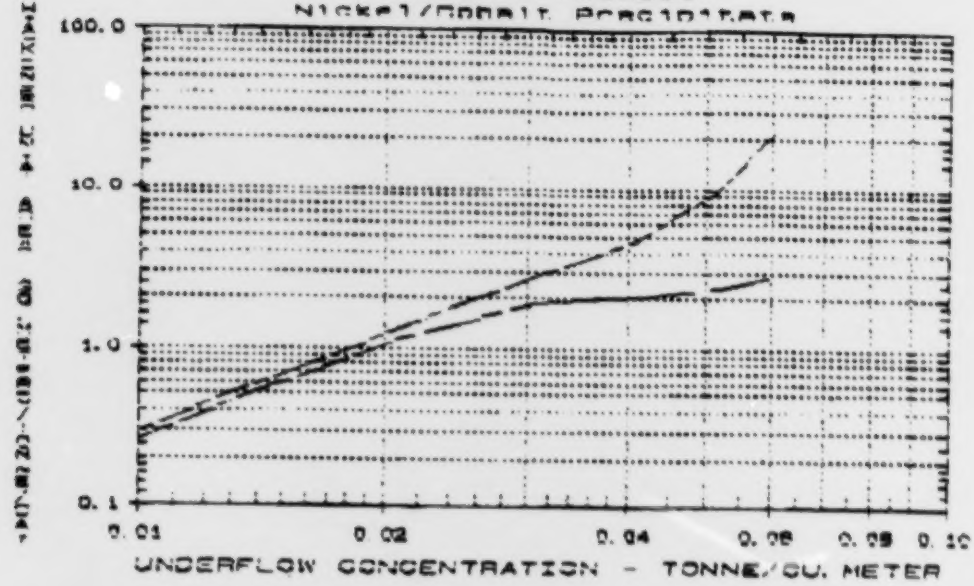
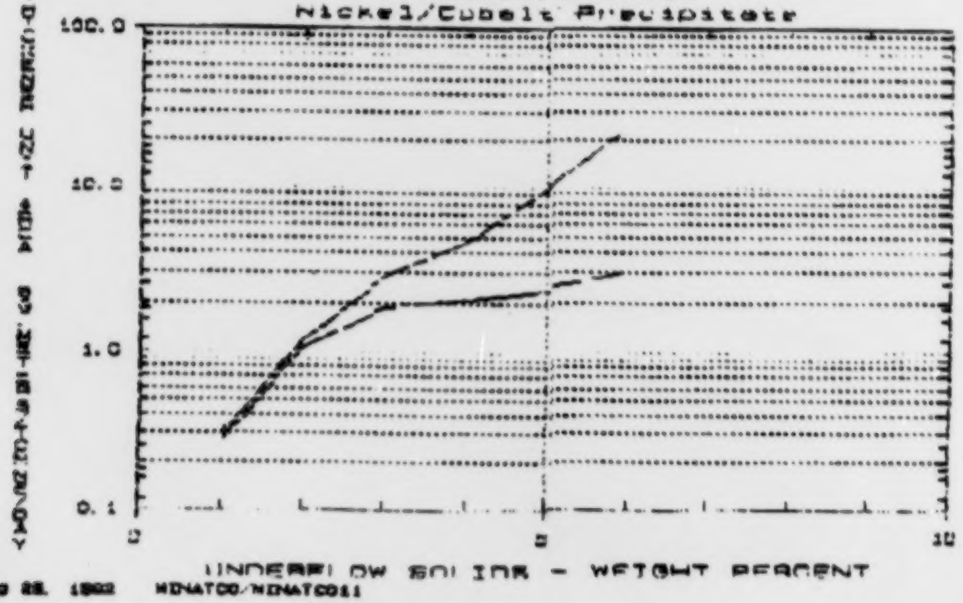


Figure ___ UNIT AREA vs PCT. UF SOLIDS
Minatco/Midwest
Nickel/Cobalt Precipitate



AUG 25, 1992 MINATCO/MINATCO11

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                         EIMCO PROCESS EQUIPMENT COMPANY
                          THICKENER TEST SUMMARY SHEET

TEST ID: Minatco/Midwest #12 Hi-Cao
         Nickel/Cobalt Precipitate                     CREATED: Jul 31. 1992
                                                       UPDATED: Aug  4. 1992
STORAGE FILE: /ROBISON/WORK/MINATCO/MINATCO12.THK
                                                            TIME (MIN)   HEIGHT (ML)
FLOCCULANT: Percol E-10                                        0.00        1995.
                               CONCENTRATION (G/L):   1.00     1.00        1660.
                               VOLUME ADDED (ML):     3.0      1.50        1440.
                               DOSAGE:              208.3  G/MT 2.00       1200.
SETTLING VESSEL SIZE (ML/FT):   1490.                          2.50         990.
UNDECANTED SLURRY VOLUME (ML):  1987.0                         3.00         825.
           SLURRY WEIGHT (G):   3115.08   TARE (G): 1117.60    4.00         700.
DECANTED SLURRY VOLUME (M ):     198.6                         5.00         630.
         SLURRY WEIGHT (G):     1326.60                        6.00         580.
DRY SOLIDS WEIGHT (G):           143.90   TARE (G):  129.10    8.00         510.
ULTIMATE INTERFACE HEIGHT (ML)   215.                         12.00         430.
                                                              18.00         340.
SPECIFIC GRAVITY SUPERNATANT      1.0000                      22.00         325.
SPECIFIC GRAVITY SOLIDS           3.6000                      28.00         300.
                                                              43.00         260.
                                                              69.00         250.
UNDERFLOW CONCENTRATION     WEIGHT % SOLIDS      CU (MT/CU.M) *******     *******
   INITIAL                        .72              .00725     *******     *******
   MINIMUM DESIRED                .72              .00725     *******     *******
   FINAL (TEST)                  5.55              .05703     *******     *******
   ULTIMATE                      6.41              .06725     *******     *******
                                                              *******     *******
  UNDERFLOW          UNDERFLOW        UNIT AREA    UNIT AREA  *******     *******
WEIGHT % SOLIDS     CU (MT/CU.M)     SQ.M/MTPD  SQ.M/MTPD CORRECTED *******  *******
                                                              *******     *******
     5.5              .05703          24.433       3.267      *******     *******
     5.0              .05187           8.817       1.983      *******     *******
     4.0              .04119           4.146       1.642      *******     *******
     3.0              .03066           1.827       1.072      *******     *******
     2.0              .02029            .692        .591      *******     *******
     1.0              .01007            .273        .246      *******     *******
```

Figure __ BATCH INTERFACE SETTLING DATA
Minatco/Midwest #12 Hi-Cap
Nickel/Cobalt Precipitate

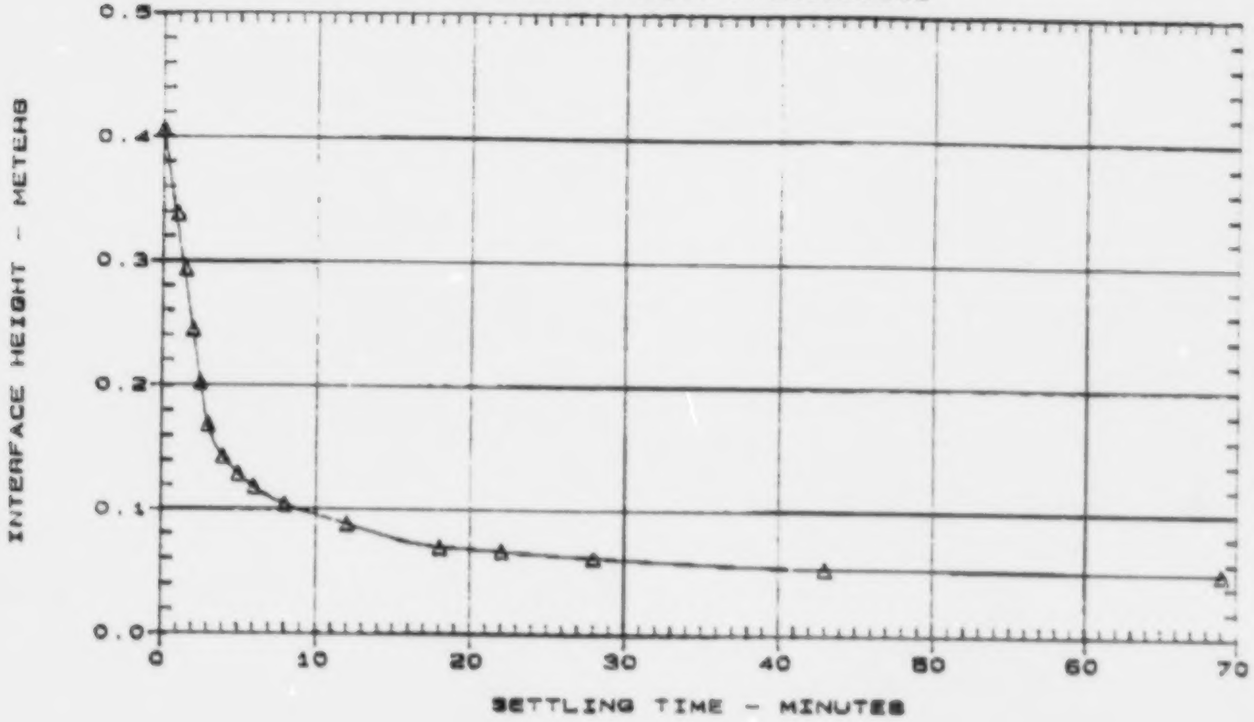
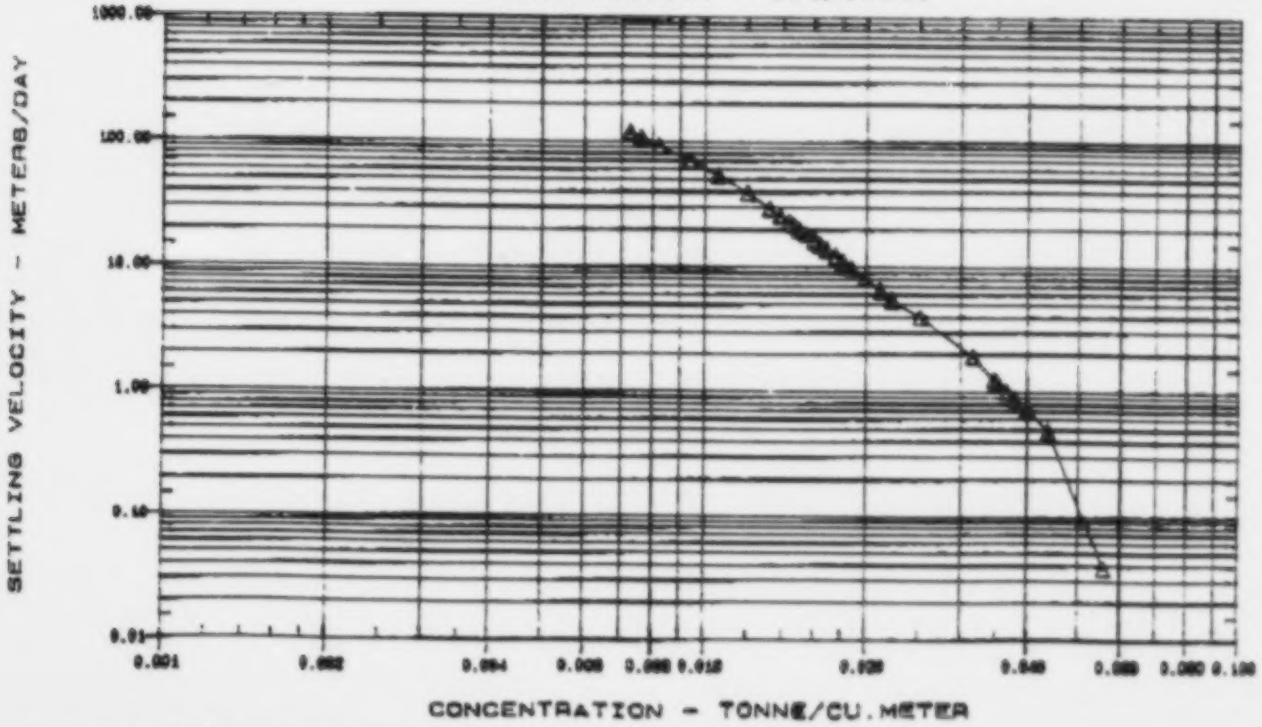


Figure __ SETTLING VEL vs CONCENTRATION
Minatco/Midwest #12 Hi-Cap
Nickel/Cobalt Precipitate



AUG 4, 1992 MINATCO/MINATCO12

Figure __ UNIT AREA vs UF CONCENTRATION
Minatco/Midwest #12 Hi-Cap
Nickel/Cobalt Precipitate

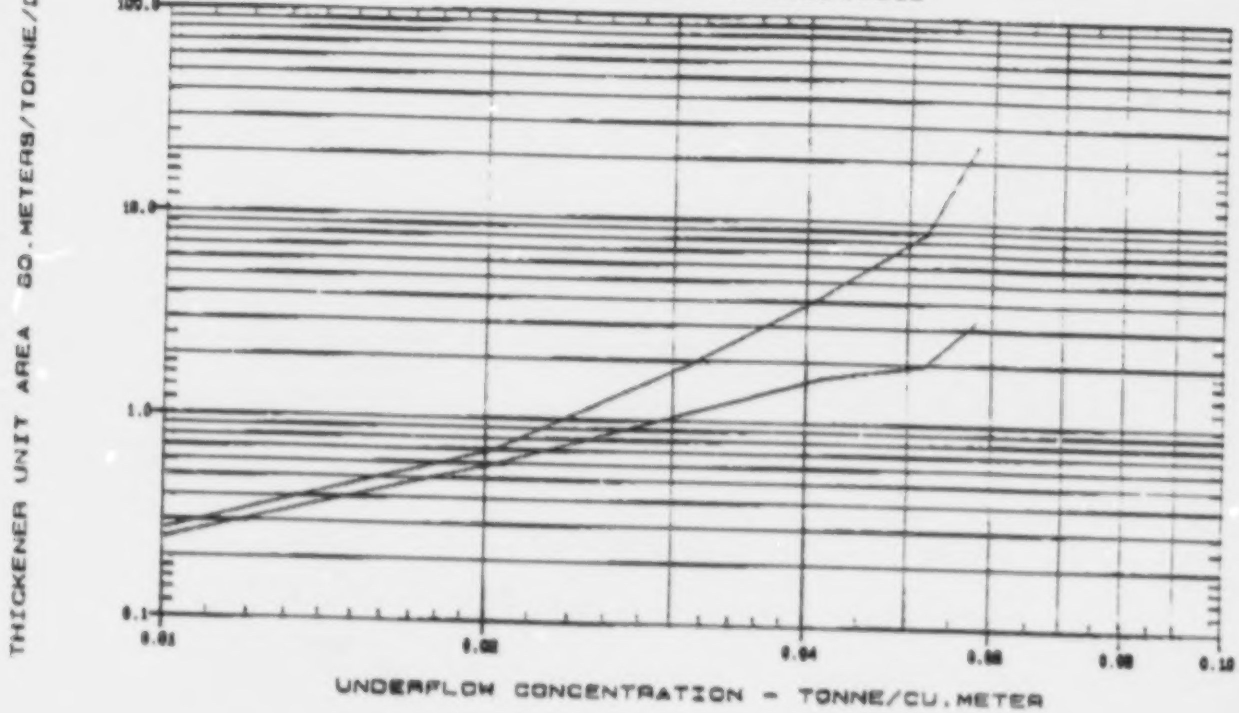
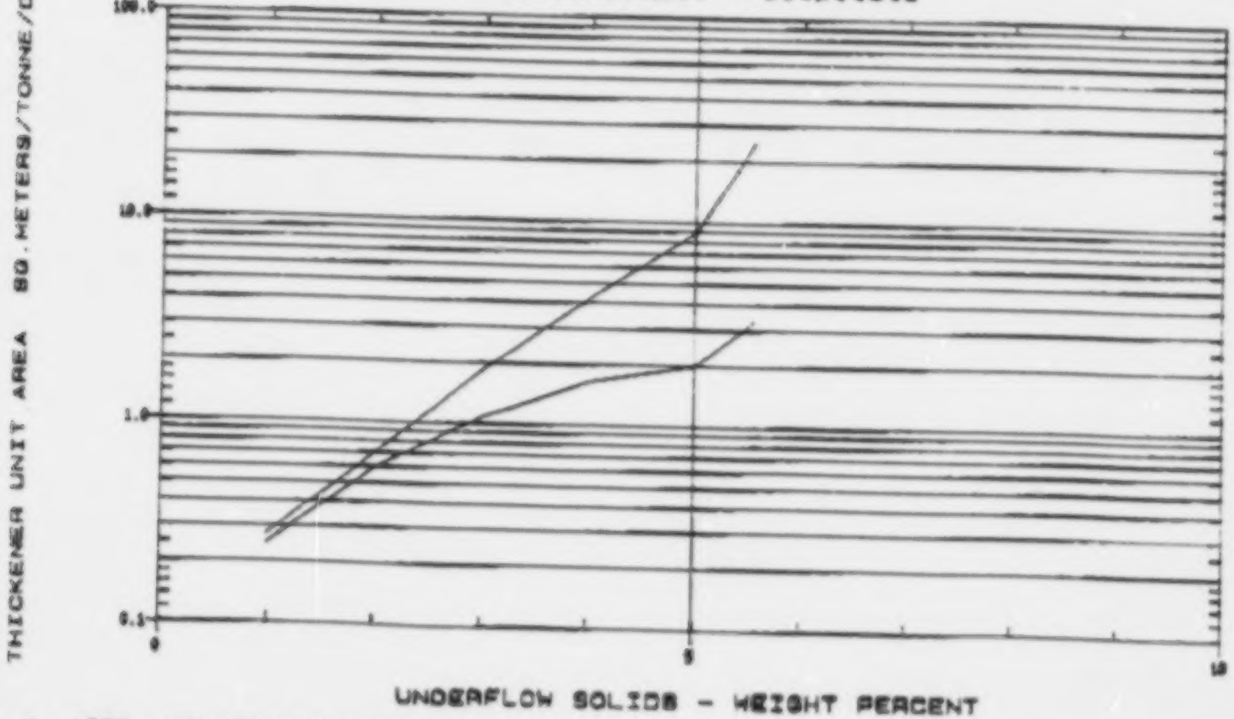


Figure __ UNIT AREA vs PCT. UF SOLIDS
Minatco/Midwest #12 Hi-Cap
Nickel/Cobalt Precipitate



SECTION 3.0

Ni/Co PRECIPITATE PRESSURE FILTRATION

DISCUSSION AND CONCLUSIONS

SECTION 3.0 - DISCUSSION & CONCLUSIONS

D) Ni/Co Precipitate Pressure Filtration

A sample of nickel/cobalt precipitate was allowed to thicken and Shiver bench-scale pressure filtration tests were conducted on the slurry. A total of two (2) tests were conducted to determine the filtration rate and other filtration characteristics of this precipitate. Attached are the filtration summary sheets and graphs for this pressure filter test work.

Feed Solids Concentration

The sample of nickel/cobalt precipitate was the same as that used in the clarification test work. The sample was allowed to thicken and it reached a density of approximately 16 wt% solids; this is a good design density.

Filter Press Sizing

The Shriver filter press was sized based upon a dry cake density of 974 kg/m^3 and a total dry solids feed rate of 278 kg/h. The total cake volume per filter cycle required is approximately 0.4 m^3, or 14 ft^3. The total cycle time is approximately 1.5 hours to produce 32 mm filter cakes. The Shriver filter press for this cycle time is a Shriver model 1200 x 12 chambers. However, we are recommending that consideration be given to a Shriver, model 1200 x 33 chambers. The larger filter press will increase the cycle time to approximately 4.5 hours which will reduce the operator attention to once or twice per shift.

Filtration Rate

The filtration rate obtained in the bench scale testing was 2.0 L/min/m^2, or 0.05 gpm/ft^2. The filter press is sized based upon the press cake holding capacity not the filtration rate. For the Shriver, model 1200 x 33 chamber filter press the back calculated filtration rate is 0.5 L/min/m^2 which is well below the actual filtration rate.

SECTION 3.0 - DISCUSSION & CONCLUSIONS

D) Ni/Co Precipitate Pressure Filtration

Final Cake Moisture

The filter cake dewatered to a final solids of 57 weight percent or 43 wt% moisture. The formed cake was air blown at 517 kPa, (75 psig), for 5 minutes. The filter design should include an air blow sequence and the air requirement during this portion of the filter cycle is approximately 18.2 $m^3/h/m^2$, (1.0 cfm/ft^2). A sample of the wet filter press cake was collected to illustrate the stability of this wet filter cake for on site handling and transportation.

Process Test Conditions

The nickel/cobalt test slurry was filtered at approximately 20 degrees centigrade, under normal process conditions the slurry temperature will likely be at approximately 40^0C. This higher filtering temperature will likely improve the final cake moisture slightly. Since the filter is sized on cake holding capacity the increase in feed temperature will not have any effect on the filter sizing.

Filter Media

A few different filter media types were tested. We found that EIMCO's polypropylene 336HS gave the best filtering characteristics and provided a clear pressate.

```
                         Shriver Test Summary
                          Wed Aug 19, 1992

ile:            C:\VJW\MINATCO\CONC4
ompany:         MIDWEST
ddress:
aterial:        Nickel /Cobalt
ilter Cloth:    336HS

ry Solids Sp.Gr.:             2.00000     Init. Cake Thickness (mm):       31.800
iquid Sp.Gr.:                 1.00000     Final Cake Thickness (mm):       31.800
hamber Volume (cu.ft):        0.00527     Dry Cake Wt % Solids:            57.053
et Cake Weight (g):            254.50     Dry Cake Dens. (lb/cu.ft):       60.799
ry Cake Weight (g):            145.20     Wet Cake Dens. (lb/cu.ft):      106.566
hamber Area (sq.ft):           0.0505     Test Temperature (Deg C):        20.000


est Name:            Filtration Test #4
ank Constant:            1.0000    Filter Loading (gal/sq.ft):      1.986
olume Units:             (mls)     Calcd Feed % Solids:            16.796

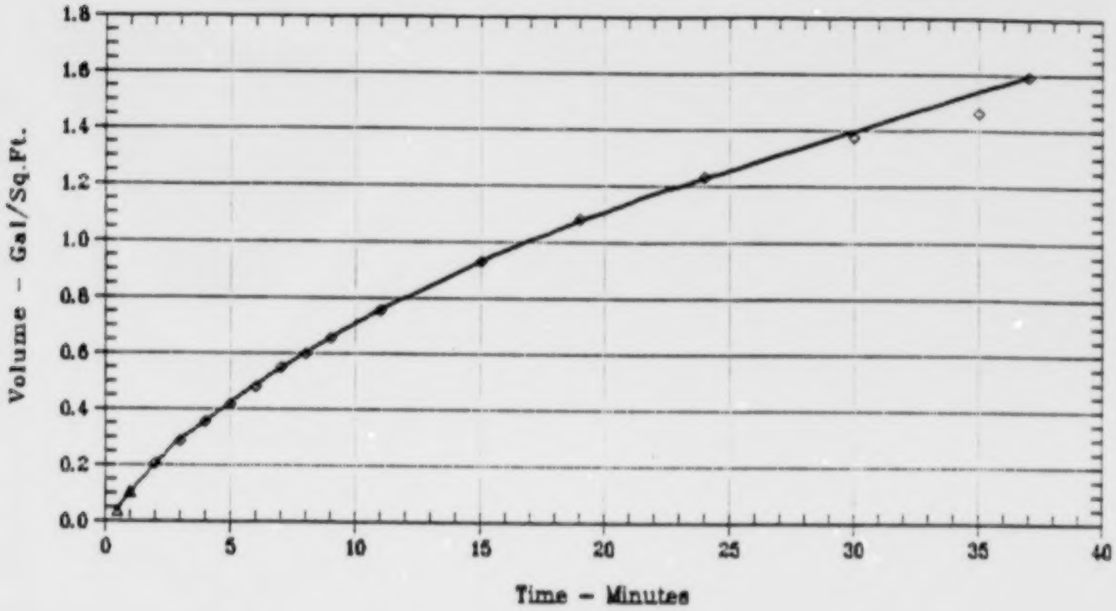
  Time      Pressure   Inc.Volume   Cum.Volume   Cum.Volume
 Minutes      PSIG        (mls)        (mls)     Gal/Sq.Ft.
   0.00         0          0.00         0.00       0.0000
   0.50        20         15.00        15.00       0.0392
   1.00        40         25.00        40.00       0.1046
   2.00        50         40.00        80.00       0.2093
   3.00        50         30.00       110.00       0.2877
   4.00        50         25.00       135.00       0.3531
   5.00        50         25.00       160.00       0.4185
   6.00        50         25.00       185.00       0.4839
   7.00        50         25.00       210.00       0.5493
   8.00        50         20.00       230.00       0.6016
   9.00        50         20.00       250.00       0.6540
  11.00        50         40.00       290.00       0.7586
  15.00        50         65.00       355.00       0.9286
  19.00        50         58.00       413.00       1.0803
  24.00        50         57.00       470.00       1.2294
  30.00        50         55.00       525.00       1.3733
  35.00        50         35.00       560.00       1.4649
  37.00        50         50.00       610.00       1.5957
```

Filtrate Volume vs Time

MIDWEST

Filtration Test #4

Wed Aug 19, 1992

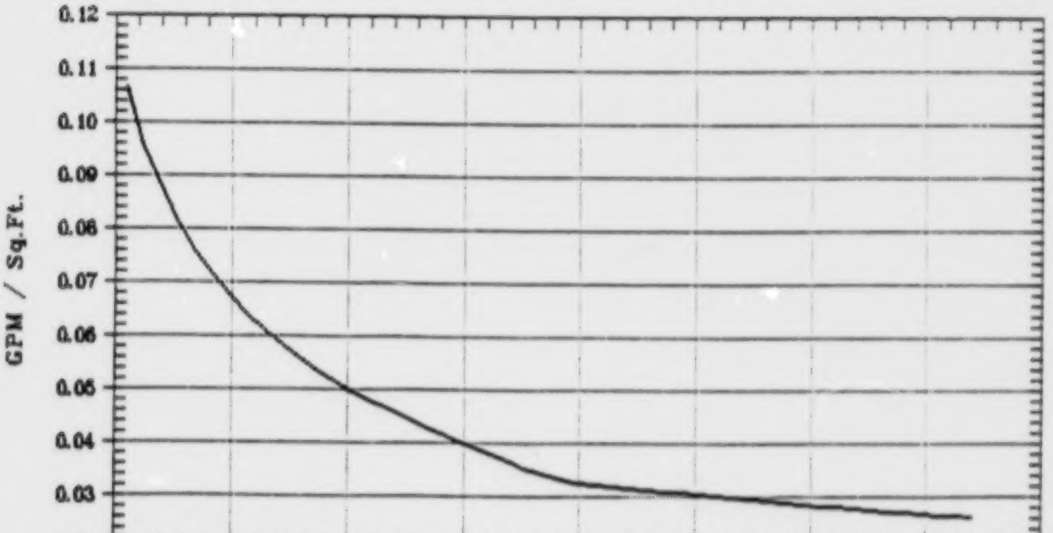


Filter Loading vs Time

MIDWEST

Filtration Test #4

Wed Aug 19, 1992



```
                   Eimco Process Equipment Company
                        Shriver Test Summary
                         Wed Aug 19, 1992

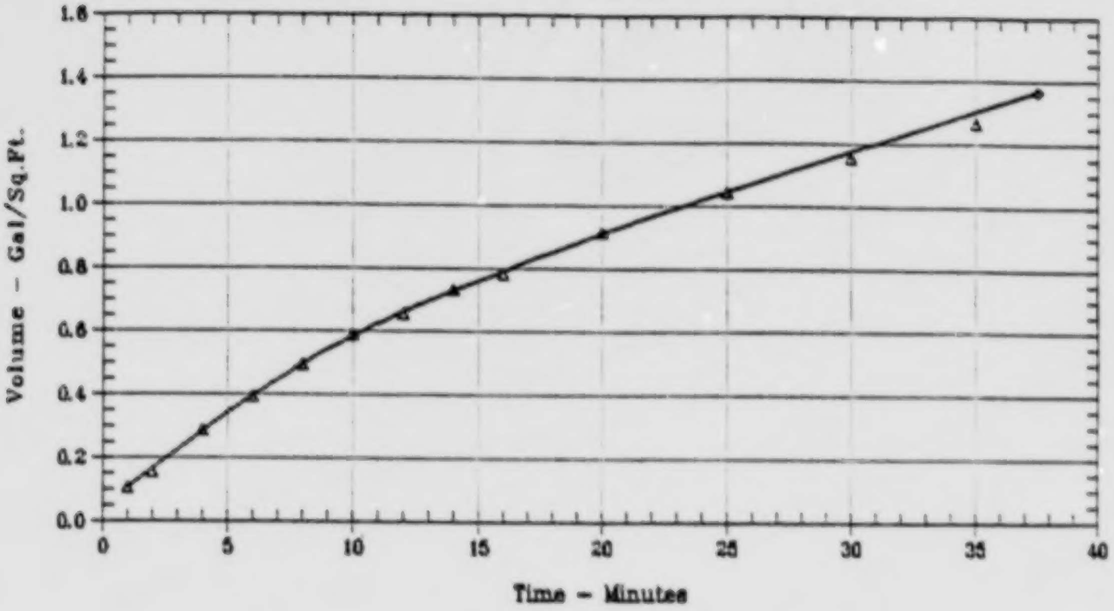
File:           C:\VJW\MINATCO\CONC5
Company:        MIDWEST
Address:
Material:       Nickel /Cobalt
Filter Cloth:   336HS

Dry Solids Sp.Gr.:             2.00000    Init. Cake Thickness (mm):     31.800
Liquid Sp.Gr.:                 1.00000    Final Cake Thickness (mm):     31.800
Chamber Volume (cu.ft):        0.00527    Dry Cake Wt % Solids:          57.053
Wet Cake Weight (g):            254.50    Dry Cake Dens. (lb/cu.ft):     60.799
Dry Cake Weight (g):            145.20    Wet Cake Dens. (lb/cu.ft):    106.566
Chamber Area (sq.ft):           0.0505    Test Temperature (Deg C):      20.000

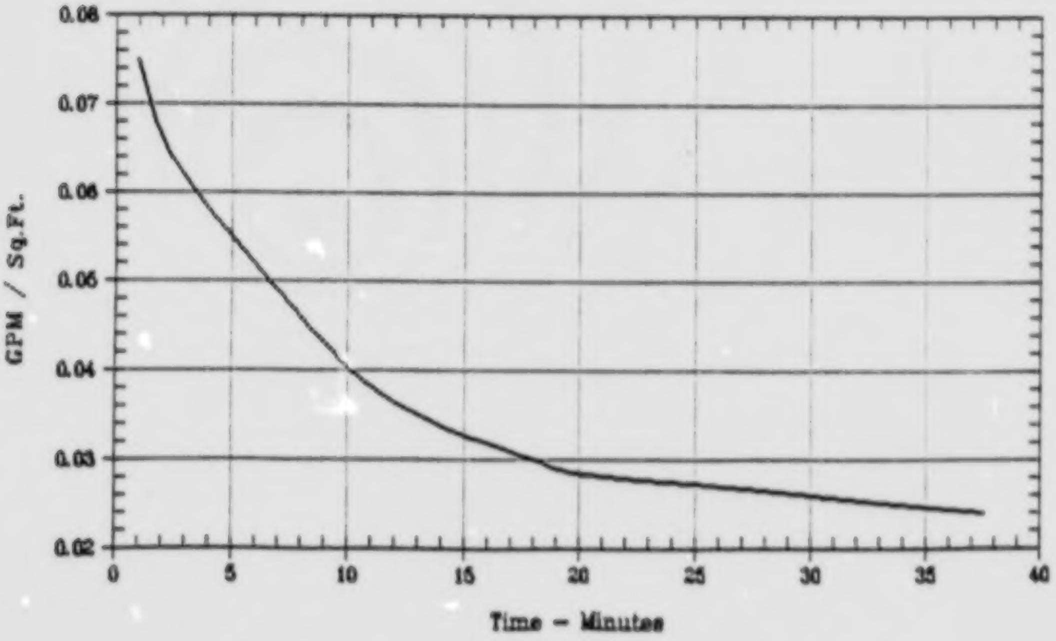
Test Name:             Filtration #5
Tank Constant:             1.0000    Filter Loading (gal/sq.ft):     1.756
Volume Units:               (mls)    Calcd Feed % Solids:           18.699

   Time      Pressure  Inc.Volume  Cum.Volume  Cum.Volume
  Minutes      PSIG        (mls)       (mls)   Gal/Sq.Ft.
   0.00          0          0.00        0.00      0.0000
   1.00         50         40.00       40.00      0.1046
   2.00         50         20.00       60.00      0.1570
   4.00         50         50.00      110.00      0.2877
   6.00         50         40.00      150.00      0.3924
   8.00         50         40.00      190.00      0.4970
  10.00         50         35.00      225.00      0.5886
  12.00         50         25.00      250.00      0.6540
  14.00         50         30.00      280.00      0.7324
  16.00         50         20.00      300.00      0.7848
  20.00         50         50.00      350.00      0.9155
  25.00         50         50.00      400.00      1.0463
  30.00         50         42.00      442.00      1.1562
  35.00         50         43.00      485.00      1.2687
  37.50         75         37.00      522.00      1.3655
```

Filtrate Volume vs Time
MIDWEST
Filtration #5
Wed Aug 19, 1992



Filter Loading vs Time
MIDWEST
Filtration #5
Wed Aug 19, 1992



SECTION 4.0

RAW DATA SHEETS MISCELLANEOUS TEST DATA

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. 19

THICKENER TEST DATA SHEET

Company: Midwest
Contact:

Test No.: 19
Date Tested: July 9/92 By: LALLASTONE
Location: LAKEFIELD RES

Material: 1ST-STAGE PRECIPITATE (Gypsum/Fe)
Object of Test: FLOC DOSE

Thickener Simulated: Hi-Cap
Picket Speed (RPH):
Flocculant Mixing Intensity: 6

TEST I.D.: 1E
FLOCCULANT: E-10
CONCENTRATION (G/L): 1
VOLUME ADDED (ML): 0.5
DOSAGE (G/MT OR LB/TON):
SETTLING VESSEL SIZE (ML/FT): 1445
UNDECANTED SLURRY VOLUME (ML): 1990
SLURRY WEIGHT (G): 2907.6 TARE: 902.6
DECANTED SLURRY VOLUME (ML): 190
SLURRY WEIGHT (G): 1088.0
DRY SOLIDS WEIGHT (G): 286.4 TARE: 258.
ULTIMATE INTERFACE HEIGHT (ML): 190

Feed Slurry:
Temperature (°C): ≈20
pH: 5.22
Description:
(27.6 gm d.s.)

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

Supernatant Description: hazy
Clear at 5'

Thickened Pulp Description: ~~hazy~~
Medium fluffy floc

Give Approximate Values, if known:
Sp. Gravity Supernatant 1.0
Sp. Gravity Solids
Minimum Desired Underflow % Solids
Initial % Solids 1.38
Final % Solids 14.89
Ultimate % Solids

Metric X English ____ Output?

REMARKS:
1+59/1=60/2= 30

	TIME MIN.	INTERFACE HEIGHT ML
1.	4:14pm 0	2000
2.	0.5	1960
3.	1.0	1870
4.	2	1680
5.	3	1470
6.	5	1155
7.	7	950
8.	9	820
9.	11	740
10.	14	640
11.	16	580
12.	20	520
13.	23	475
14.	27	410
15.	4:46 32	360
16.	5:06 52	290
17.	5:15 61	260
18.	5:40 86	225
19.	6:45 151	205
20.	7:35pm 201	195
21.		
22.		
23.		
24.		
25.		
26.		
27.		
28.		
29.		
30.		
31.		

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. 20

THICKENER TEST DATA SHEET

Company: MIDWEST
Test No.:
Contact:
Date Tested: JULY 9/92 By: W.W. STONE
Location:
Material: 1ST - STAGE PRECIPITATE
Object of Test: FLOC DOSE

Thickener Simulated: Hi-CAP
Picket Speed (RPH):
Flocculant Mixing Intensity:

TEST I.D.: 4E
FLOCCULANT: PERCOL E-10
CONCENTRATION (G/L): 1
VOLUME ADDED (ML): 1.0
DOSAGE (G/MT OR LB/TON):
SETTLING VESSEL SIZE (ML/FT): 1498
UNDECANTED SLURRY VOLUME (ML): 1995
SLURRY WEIGHT (G): 3141.5 TARE: 1117.
DECANTED SLURRY VOLUME (ML): 180
SLURRY WEIGHT (G): 1306.3
DRY SOLIDS WEIGHT (G): 234.7 TARE: 205.3
ULTIMATE INTERFACE HEIGHT (ML): 190

Feed Slurry:
Temperature (°C): ≈ 20°C
pH: 5.22
Description:
(29.4g d.s.)

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

	TIME MIN.	INTERFACE HEIGHT ML
1. 4:25pm	0	2000
2.	0.5	1910
3.	1.0	1770
4.	1.5	1630
5.	2.0	1490
6.	3	1250
7.	4	1060
8.	5	940
9.	6	860
10.	7	780
11.	[illegible]	730
12.	10	620
13.	13	520
14.	15	460
15.	20	375
16.	24	340
17. 5:00	35	285
18. 5:15	50	270
19. 5:40	75	230
20. 6:45	140	220
21. 7:35pm	190	210
22.		
23.		
24.		
25.		
26.		
27.		
28.		
29.		
30.		
31.		
32.		

Supernatant Description: Fairly clear at 2'

Thickened Pulp Description: loose fluffy floc

Give Approximate Values, if known:
Sp. Gravity Supernatant 1.0
Sp. Gravity Solids
Minimum Desired Underflow % Solids
Initial % Solids ~~[illegible]~~ 1.45
Final % Solids 15.6
Ultimate % Solids

Metric X English ___ Output?

REMARKS:
20 + 58 = 60/2 30 [illegible]

ENVIROTECH

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. 21

THICKENER TEST DATA SHEET

Company: MIDWEST

Contact:

Test No.:

Date Tested: JULY 9/92 By: W.W. STONE

Location: LAKEFIELD RES.

Material: 1ST - STAGE PRECIPITATE

Object of Test: FLOC DOSE

Thickener Simulated: Hi Cap

Picket Speed (RPH):

Flocculant Mixing Intensity:

Feed Slurry:

Temperature (°C): ≈20

pH: 5.22

Description:

(25.9 gms d.s.)

TEST I.D.: 5A

FLOCCULANT: PERCOL E-10

CONCENTRATION (G/L): 1

VOLUME ADDED (ML): 1.5

DOSAGE (G/MT OR LB/TON):

SETTLING VESSEL SIZE (ML/FT): 1527

UNDECANTED SLURRY VOLUME (ML):

SLURRY WEIGHT (G): 3121.8 TARE: 1101.2

DECANTED SLURRY VOLUME (ML): 165

SLURRY WEIGHT (G): 1280.25

DRY SOLIDS WEIGHT (G): 156.1 TARE: 130.2

ULTIMATE INTERFACE HEIGHT (ML): 170

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

		TIME MIN.	INTERFACE HEIGHT ML
1.	4:43	0	2000
2.		0.5	1870
3.		1.0	1660
4.		1.5	1460
5.		2.0	1270
6.		3	970
7.		4	815
8.		5	710
9.		7	580
10.		16	300
11.		24.	—
12.	5:15.	32	240
13.	5:40	57	210
14.	6:45	122	190
15.	7:35pm	172	180
16.			
17.			
18.			
19.			
20.			
21.			
22.			
23.			
24.			
25.			
26.			
27.			
28.			
29.			
30.			
31.			
32.			

Supernatant Description:

Thickened Pulp Description: Very large floc

Give Approximate Values, if known:

Sp. Gravity Supernatant 1.0

Sp. Gravity Solids

Minimum Desired Underflow % Solids

Initial % Solids 1.28

Final % Solids 14.46

Ultimate % Solids

Metric X English ___ Output?

REMARKS:

3+57 = 60/2 = 30 mls All

ENVIROTECH

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. 22

THICKENER TEST DATA SHEET

Company: MIDWEST

Contact:

Test No.: 22

Date Tested: July 9/92 By: WWStma

Location: Wakefield Kan.

Material: 1st-STAGE PRECIPITATE

Object of Test: INCREASED FEED SOLIDS CONC.

Thickener Simulated:

Picket Speed (RPH):

Flocculant Mixing Intensity:

Feed Slurry:

Temperature (°C):

pH:

Description:

(60.9 gms d.s.)

TEST I.D.: 3E

FLOCCULANT: PERCOL E-10

CONCENTRATION (G/L): 1

VOLUME ADDED (ML): 2

DOSAGE (G/MT OR LB/TON):

SETTLING VESSEL SIZE (ML/FT): 1532

UNDECANTED SLURRY VOLUME (ML): 1995

SLURRY WEIGHT (G): 3138.6 TARE: 1094.6

DECANTED SLURRY VOLUME (ML): 370

SLURRY WEIGHT (G): 1502.0

DRY SOLIDS WEIGHT (G): 267.7 TARE: 206.8

ULTIMATE INTERFACE HEIGHT (ML): 390

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

	TIME MIN.	INTERFACE HEIGHT ML
1.	5:11pm 0	~~2000~~ 2005
2.	0.5	2000
3.	1.0	1990
4.	3	1910
5.	5	1735
6.	6	1635
7.	7.5	1480
8.	11.5	1160
9.	14	1020
10.	17	875
11.	24	680
12.	30	595
13.	41	510
14.	55	460
15.	93	420
16.	7:35pm 143	400
17.		
18.		
19.		
20.		
21.		
22.		
23.		
24.		
25.		
26.		
27.		
28.		
29.		
30.		
31.		
32.		

Supernatant Description: Clear

Thickened Pulp Description: Large floc

Give Approximate Values, if known:

Sp. Gravity Supernatant 1.0

Sp. Gravity Solids ≈ 2.2

Minimum Desired Underflow % Solids

Initial % Solids 2.98

Final % Solids 14.55

Ultimate % Solids

Metric X English ___ Output?

REMARKS:

4 + 56 = 60/2 = 30 added.

EIMCO Process Equipment Company

VACUUM FILTRATION TEST DATA SHEET

Company [illegible]
Address

Job Name:
Test Name:
Date Tested [illegible]
By [illegible]
Location [illegible]

MATERIAL TO BE FILTERED:
% Suspended Solids, Consisting of
% Liquid, Consisting of

Slurry Temperature °C/°F
Slurry pH
Specific Gravity of Liquid
% Dissolved Solids in Liquid
% Total Solids of Slurry

1st STAGE [illegible]
TESTED AS REC'D

Filter Area [illegible] Sq Ft
Filter Cloth
Slurry Feeding Technique Bottom Feed ☐
Top Feed ☑
Air Flow Meter Gas Meter ☐ Rotameter ☐
Air Leakage: CFM @ " Hg Vac.
Avg. Filtrate Suspended Solids, mg/l

TEST NO	FILTERING VAC. IN HG			FILTERING TIME - min or sec					AIR METER READING	FILTRATE VOLUME ML	WASH VOLUME ML	CAKE THICKNESS in or mm	CAKE WEIGHT GRAMS			CAKE MOISTURE %	AIR FLOW CFM SQ FT	DRY WT × 100 / WET WT • FILTRATE WT	W DRY LBS PER SQ FT	θd/W min-ft² per dry lbs			
	FORM	WASH	DRY	FORM	PRE-WASH DRY	WASH	DRY	CAKE CRACKS					Tare	Wet	Dry								
1	20	20	16	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	44	15	-1/8	[illegible]	129.7 [illegible]	47.1 213.0	63.7		15.8					
2	20		[illegible]	14	4	[illegible]	15	[illegible]	—	[illegible]	60	3/8	[illegible]	292.7	192.8							[illegible]	
3	[illegible]		[illegible]	[illegible]	3	13	[illegible]	[illegible]	—	132	[illegible]	1/4	[illegible]	[illegible]	192.0							[illegible]	
4			[illegible]	46	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	13/16	[illegible]	177.9 [illegible]	65.1 238.1	63.4		15.7				100	
5	[illegible]		[illegible]	[illegible]	[illegible]	5	[illegible]	[illegible]	[illegible]	18	20	5/16	[illegible]	[illegible]	188.9							[illegible]	
6	20		16	14	[illegible]	63	30	[illegible]	801	[illegible]	[illegible]	1/2	[illegible]	[illegible]	205.6							[illegible]	
7	20		[illegible]	15	[illegible]	41			[illegible]	200	150	1/2	[illegible]	[illegible]	47.6								
8	20		16	14	1	[illegible]			[illegible]	[illegible]	[illegible]	1/2	[illegible]	[illegible]	44.3								
9	[illegible]		[illegible]	15	—	[illegible]			[illegible]	126	15	1/2	[illegible]	[illegible]	53.0								
10	20		[illegible]	[illegible]	[illegible]	16			[illegible]	[illegible]	50	1/2	[illegible]	115.3	46.7								

REMARKS [illegible]

[illegible] -11

5 = 184.0

Company [illegible]

Address

EIMCO Process Equipment Company

VACUUM FILTRATION TEST DATA SHEET

Test Name:

Date Tested

By

Location

MATERIAL TO BE FILTERED:

% Suspended Solids, Consisting of

% Liquid, Consisting of

Slurry Temperature °C/°F

Slurry pH

Specific Gravity of Liquid

% Dissolved Solids in Liquid

% Total Solids of Slurry

1st Stage Precipitate
Tested as Received

Filter Area Sq Ft

Filter Cloth

Slurry Feeding Technique Bottom Feed ☐ Top Feed ☐

Air Flow Meter: Gas Meter ☐ Rotameter ☐

Air Leakage: CFM @ " Hg Vac.

Avg. Filtrate Suspended Solids, mg/l

TEST NO	FILTERING VAC. IN HG FORM	FILTERING VAC. IN HG WASH	FILTERING VAC. IN HG DRY	FILTERING TIME - min or sec FORM	FILTERING TIME - min or sec PRE WASH DRY	FILTERING TIME - min or sec WASH	FILTERING TIME - min or sec DRY	FILTERING TIME - min or sec CAKE CRACKS	AIR METER READING	FILTRATE VOLUME ML	WASH VOLUME ML	CAKE THICKNESS IN OR MM	CAKE WEIGHT GRAMS Tare	CAKE WEIGHT GRAMS Wet	CAKE WEIGHT GRAMS Dry	CAKE MOISTURE %	AIR FLOW CFM SQ FT	DRY WT × 100 / WET WT + FILTRATE WT	W DRY LBS PER SQ FT	θd/W min-ft² per dry lbs		[illegible]	
11	20	20	16	14	2	6	[illegible]	[illegible]	[illegible]	174	25	1/2	[illegible]	[illegible]	50.3								
12	20	—	16	16	—	—	30	[illegible]	[illegible]	[illegible]	0	1/2	[illegible]	[illegible]	249.4							[illegible]	
13	15	15	15	4	3	5	110 20	[illegible]		30	20	3/16	[illegible]	[illegible]	96.2								[illegible]
14	15	|	15	[illegible]	3	12	[illegible]	[illegible]	[illegible]	146	50	5/16	[illegible]	[illegible]	118.9								
15	15	|	15	11	3	21	[illegible]	[illegible]	[illegible]	200	75	3/8	[illegible]	[illegible]	171.0								
16	15	[illegible]	[illegible]	12	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	5/8	[illegible]	[illegible]	132.1								
7																							
8																							
9																							
0																							

REMARKS

E-643 Rev. 1/86

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. [illegible]

THICKENER TEST DATA SHEET

Company: [illegible]

Contact:

Test No.: [illegible]

Date Tested: [illegible] By: [illegible]

Location: LAKEFIELD [illegible]

Material: [illegible]

Object of Test:

Thickener Simulated:

Picket Speed (RPH):

Flocculant Mixing Intensity:

TEST I.D.: 1A

FLOCCULANT: None

CONCENTRATION (G/L): —

VOLUME ADDED (ML): —

DOSAGE (G/MT OR LB/TON): —

SETTLING VESSEL SIZE (ML/FT): 1445

UNDECANTED SLURRY VOLUME (ML): [illegible]

SLURRY WEIGHT (G): [illegible] TARE: [illegible]

DECANTED SLURRY VOLUME (ML): [illegible]

SLURRY WEIGHT (G): [illegible]

(21.2[illegible]) DRY SOLIDS WEIGHT (G): 148.6 TARE: [illegible]

ULTIMATE INTERFACE HEIGHT (ML): 235

Feed Slurry:

Temperature (°C):

pH:

Description:

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

Supernatant Description:

Thickened Pulp Description:

Give Approximate Values, if known:

Sp. Gravity Supernatant 1.0

Sp. Gravity Solids 2.2 ?

Minimum Desired Underflow % Solids

Initial % Solids 2.19

Final % Solids 8.38

Ultimate % Solids

Metric X English ___ Output?

REMARKS:

	TIME MIN.	INTERFACE HEIGHT ML
1.	[illegible] 0	[illegible]
2.	[illegible]	[illegible]20
3.	[illegible]	72
4.	[illegible]	[illegible]
5.	[illegible]	[illegible]
6.	3	[illegible]
7.	4	[illegible]
8.	5	[illegible]
9.	7	[illegible]
10.	11	425
11.	14	390
12.	17	[illegible]
13.	101	275
14.	[illegible] 45 [illegible] 179	250
15.	5 [illegible] 330	235
16.		
17.		
18.		
19.		
20.		
21.		
22.		
23.		
24.		
25.		
26.		
27.		
28.		
29.		
30.		
31.		
32.		

ENVIROTECH

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. [illegible]

THICKENER TEST DATA SHEET

Company: [illegible]

Contact:

Test No.: [illegible]

Date Tested: [illegible] By: [illegible]

Location: [illegible]

Material: [illegible]

Object of Test:

Thickener Simulated: [illegible]

Picket Speed (RPH): –

Flocculant Mixing Intensity: –

Feed Slurry:

Temperature (°C): 27

pH: 3.6

Description:

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

Supernatant Description: [illegible] @ 10' [illegible]

Thickened Pulp Description: [illegible]

Give Approximate Values, if known:

Sp. Gravity Supernatant 1.0

Sp. Gravity Solids 3.6

Minimum Desired Underflow % Solids

Initial % Solids

Final % Solids

Ultimate % Solids

Metric X English ____ Output?

REMARKS: [illegible]

TEST I.D.: 1C

FLOCCULANT: [illegible]

CONCENTRATION (G/L): –

VOLUME ADDED (ML): –

DOSAGE (G/MT OR LB/TON): –

SETTLING VESSEL SIZE (ML/FT): [illegible]

UNDECANTED SLURRY VOLUME (ML): [illegible]

SLURRY WEIGHT (G): 2846.2 TARE: [illegible]

DECANTED SLURRY VOLUME (ML): [illegible]

SLURRY WEIGHT (G): [illegible]

DRY SOLIDS WEIGHT (G): 190.5 TARE: [illegible]

ULTIMATE INTERFACE HEIGHT (ML): [illegible]

		TIME MIN.	INTERFACE HEIGHT ML
1.	[illegible] 11Pm	0	1005
2.		[illegible]	[illegible]40
3.		1.0	[illegible]00
4.		2	[illegible]00
5.		3 4	1330
6.		5	[illegible]10
7.		7	1170
8.		9	330
9.		11	[illegible]
10.		13	[illegible]
11.		[illegible]	[illegible]10
12.		[illegible]	550
13.		20	1 –
14.		24	460
15.	6:41	30	[illegible]
16.	6:46Pm	35	335
17.	[illegible] Pm	51	340
18.	[illegible]	58	[illegible]
19.	[illegible]	86	[illegible]
20.	[illegible] Pm	116	[illegible]50
21.	3 [illegible] 5AM	934	205
22.			
23.			
24.			
25.			
26.			
27.			
28.			
29.			
30.			
31.			
32.			

ENVIROTECH

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. [illegible]

THICKENER TEST DATA SHEET

Company: [illegible]
Contact:
Test No.: [illegible]
Date Tested: [illegible] By: [illegible]
Location: [illegible]

Material: [illegible]
Object of Test: [illegible]

Thickener Simulated: [illegible]
Picket Speed (RPH):
Flocculant Mixing Intensity: [illegible]

Feed Slurry:
Temperature (°C): [illegible]37
pH: [illegible]
Description:

TEST I.D.: 2C
FLOCCULANT: [illegible]
CONCENTRATION (G/L): 1
VOLUME ADDED (ML): 1.2
DOSAGE (G/MT OR LB/TON):
SETTLING VESSEL SIZE (ML/FT): [illegible]
UNDECANTED SLURRY VOLUME (ML): [illegible]
SLURRY WEIGHT (G): [illegible]377.2 TARE: [illegible]
DECANTED SLURRY VOLUME (ML): [illegible]
SLURRY WEIGHT (G): 1056.0
DRY SOLIDS WEIGHT (G): $\boxed{45.8}$ TARE: [illegible]
ULTIMATE INTERFACE HEIGHT (ML): [illegible]

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

Supernatant Description: [illegible]
[illegible]
[illegible]

Thickened Pulp Description:

Give Approximate Values, if known:
Sp. Gravity Supernatant
Sp. Gravity Solids
Minimum Desired Underflow % Solids
Initial % Solids
Final % Solids
Ultimate % Solids

Metric____ English____ Output?

REMARKS: [illegible]

	TIME MIN.	INTERFACE HEIGHT ML
1.	[illegible] 0	1905
2.	1	1830
3.	2	1720
4.	3	1520
5.	5	1030
6.	6	[illegible]
7.	8	[illegible]
8.	11	580
9.	14	525
10.	17	[illegible]
11.	20	[illegible]
12.	27	[illegible]
13.	30	[illegible]
14.	[illegible] 37	[illegible]
15.	[illegible] 54	[illegible]
16.	7:37 72	270
17.	[illegible] 102	250
18.	[illegible] 05 min 220	210
19.		
20.		
21.		
22.		
23.		
24.		
25.		
26.		
27.		
28.		
29.		
30.		
31.		
32.		

ENVIROTECH

EIMCO PROCESS MACHINERY DIVISION
ENVIROTECH CORPORATION

Table No. 1

THICKENER TEST DATA SHEET

Company: [illegible]
Contact:
Test No.: 11
Date Tested: [illegible]
By: [illegible]
Location: [illegible]
Material: [illegible]
Object of Test: [illegible]

Thickener Simulated: [illegible]
Picket Speed (RPH):
Flocculant Mixing Intensity: 4

Feed Slurry:
Temperature (°C): [illegible]
pH: [illegible]
Description:

TEST I.D.: [illegible]
FLOCCULANT: [illegible]
CONCENTRATION (G/L): 1
VOLUME ADDED (ML):
DOSAGE (G/MT OR LB/TON):
SETTLING VESSEL SIZE (ML/FT): [illegible]
UNDECANTED SLURRY VOLUME (ML): 1970
SLURRY WEIGHT (G): [illegible] TARE: [illegible]
DECANTED SLURRY VOLUME (ML): [illegible]
SLURRY WEIGHT (G): 12[illegible]
DRY SOLIDS WEIGHT (G): 84.9 TARE: [illegible]
ULTIMATE INTERFACE HEIGHT (ML): [illegible]

Particle Size Distribution

Mesh	Weight %	Mesh	Weight %

Supernatant Description:

Thickened Pulp Description: [illegible]
[illegible]

Give Approximate Values, if known:
Sp. Gravity Supernatant 1.0
Sp. Gravity Solids 3.59
Minimum Desired Underflow % Solids
Initial % Solids
Final % Solids
Ultimate % Solids

Metric____ English____ Output?

REMARKS:
4 + [illegible]

	TIME MIN.	INTERFACE HEIGHT ML
1.	[illegible] 0	1335.
2.	1	1750
3.	1.5	1570
4.	2	[illegible]370
5.	3	[illegible]50
6.	4	730
7.	5	645
8.	6	[illegible]35
9.	8	[illegible]
10.	10	[illegible]
11.	13	420
12.	16	390
13.	23	320
14.	32	[illegible]
15.	40	[illegible]
16.	7:37 60	250
17.	[illegible]07pm 90	235
18.	[illegible]35am [illegible]08	21[illegible]
19.		
20.		
21.		
22.		
23.		
24.		
25.		
26.		
27.		
28.		
29.		
30.		
31.		
32.		

E-1841A Rev. 1-83

EIMCO Process Equipment Company

EIMCO PROCESS EQUIPMENT COMPANY
LABORATORY PRESSURE FILTRATION DATA

Customer: MINATCO / MIDWEST
Material: Ni/Co CARBONATE
Cloth: 12oz Needlefelt

Test No: 1
Test Date: July 9'92
Slurry Solids, wt%: ______

Laboratory Test Data:

Chamber Area, ft^2 ______
Cake Thickness, mm
Final: 2"
Initial: ______
Dry Solids Density, g/cc: ______
Liquid Density, g/cc: ______

Data: g-ml ______ kg-l ______

Cake Weight:	Total	Part	Tare
Wet:	~~[illegible]~~	g 370.0	172.9
Dry:		223.9	

Line # of Constant Pressure: ______
Output: Metric X English ______

[illegible] wt = 370.0
Dry wt = 223.9
60.5 wt% solids

	Time minutes	Pressure psig	Volume
1.	2	25	140
3.	3	50	180
5.	4	75	220
7.	5.5	75	265
9.	7	80	310
11.	8	90	335
13.	10	90	360
15.	~~AIR BLOW~~	~~100~~	390
17.	AIR BLOW	100	420
19.	2'		

	Time minutes	Pressure psig	Volume
2.			
4.			
6.			
8.			
10.			
12.			
14.			
16.			
18.			
20.			

Filtrate pH: 8.5

Filtrate Solids, mg/l: ______

* Note: [illegible]

Comments: (cake/filtrate description, chemical addition, etc.)

Test terminated @ 10'.

SAMPLE # S-1 Tare W

* actual cake THICKNESS = 1/2 each side slurry in center.

E-1840

EIMCO Process Equipment Company

EIMCO PROCESS EQUIPMENT COMPANY
LABORATORY PRESSURE FILTRATION DATA

Customer: MIDWEST

Material: Ni/Co Carbonate Slurry

Cloth: 12oz Needlefelt

Test No: 2

Test Date: JULY 9/92

Slurry Solids, wt%: ______

Laboratory Test Data:

Chamber Area, ft^2 ______

Cake Thickness, mm

Final: Actual 7/16 / side.

Initial: ______

Dry Solids Density, g/cc: ______

Liquid Density, g/cc: ______

Data: g-ml ______ kg-l ______

Cake Weight:	Total	Part	Tare
Wet:		237.9	131.8
Dry:		156.0	

Line # of Constant Pressure: ______

Output: Metric X English ______

65.6 wt % solids

	Time minutes	Pressure psig	Volume		Time minutes	Pressure psig	Volume
1.	0.5	30	30	2.	End Test		250
3.	1.15	40	70	4.	3' AIR BLOW		255
5.	2	50	95	6.			
7.	2.5	60	115	8.			
9.	3.0	60	130	10.			
11.	3.5	75	140	12.			
13.	40	75	~~140~~ 150	14.			
15.	5	85	175	16.			
17.	6	90	195	18.			
19.	7	95	215	20.			

Filtrate pH: 7.5

Filtrate Solids, mg/l: ______

* Not a good run

Comments: (cake/filtrate description, chemical addition, etc.)

Use 1¼" Shim.

Run # S-2

Clarity not good

Pump Stall @ 6'-20"

Terminated Test @ 7'-0"

* Side slurry in center.

E-1840

EIMCO PROCESS EQUIPMENT COMPANY
LABORATORY PRESSURE FILTRATION DATA

Customer: MIDWEST
Material: Ni/Co CARBonate
Cloth: 336 HS.

Test No: 3
Test Date: July 9'92
Slurry Solids, wt%: ___

Laboratory Test Data:

Chamber Area, ft²: ~1
Cake Thickness, mm: [illegible]
Final: ___
Initial: ___
Dry Solids Density, g/cc: ___
Liquid Density, g/cc: ___

Data: g-ml ___ kg-l ___

Cake Weight:	Total	Part	Tare
Wet:		244.2	139.9
Dry:		164.21	

Line # of Constant Pressure: ___
Output: Metric ___ English ___

Final 67.2 wt% solids
Feed Solids = 27.9 wt%

	Time minutes	Pressure psig	Volume		Time minutes	Pressure psig	Volume
1.	0.5	10	25	2.	AIR BLOW	6	355 Final Volume
3.	1.0	25	35	4.			
5.	2.0	30	65	6.			
7.	3.0	50	100	8.			
9.	4.0	60	130	10.			
11.	5.0	~~70~~ 80	160	12.			
13.	6.0	80	170	14.			
15.	7.	85	185	16.			
17.	8	90	195	18.			
19.	9	95	225	20.			

Filtrate pH: 8.5

Filtrate Solids, mg/l: ___

Not a good run

S-3

Comments: (cake/filtrate description, chemical addition, etc.)

Try diff. Cloth.
filtrate cleaner with this media.
Bad flow 5:45

Cake THKNESS
5/16.

E-1840

EIMCO Process
Equipment
Company

EIMCO PROCESS EQUIPMENT COMPANY
LABORATORY PRESSURE FILTRATION DATA

Customer: MIDWEST
Material: Ni/Co Carb.
Cloth: 336 HS

Test No: 4
Test Date: July 9/92
Slurry Solids, wt%: ______

Laboratory Test Data:

Chamber Area, ft^2 ______
Cake Thickness, mm
Final: 1 1/4
Initial: ______
Dry Solids Density, g/cc: ______
Liquid Density, g/cc: ______

Data: g-ml ______ kg-l ______

Cake Weight:	Total	Part	Tare
Wet:		254.5	93.0
Dry:		145.2	

Line # of Constant Pressure: ______
Output: Metric ______ English ______

Final Solids 57.1
Feed Solids 16.8 wt%

	Time minutes	Pressure psig	Volume		Time minutes	Pressure psig	Volume		
1.	0.5	25	15	2.	10	50	270	(50) 20	42
3.	1.0	45	40	4.	11	50	290	21	44
5.	2.0	50	80	6.	12	50	305	22	45
7.	3.0	50	110	8.	13	50	320	24	47
9.	4	50	135	10.	14	50	340	26	49
11.	5	50	160	12.	15	50	355	30	52
13.	6	50	185	14.	16	50	370	32	53
15.	7	50	210	16.	17	50	385	35	56
17.	8		230	18.	18	50	400		
19.	9		250	20.	19	50	413		

2' min air blow

air blow = 5
Liquor

Filtrate pH: 8.5

Filtrate Solids, mg/l: ______

Total volume = 610 ml.

Comments: (cake/filtrate description, chemical addition, etc.)

Had 2212 gms slurry
Add 30 gms Lime
(S-4 sample)

FILTRATE clear.
Terminate test @ 35'

@ 31 min vacuum
from to 75

break thru = 45 secs

E-1840

EIMCO Process Equipment Company

EIMCO PROCESS EQUIPMENT COMPANY
LABORATORY PRESSURE FILTRATION DATA

Customer: MIDWEST
Material: Ni/Co Carbonate
Cloth: 336 HS

Test No: 5
Test Date: July 9/92
Slurry Solids, wt%: ______

Laboratory Test Data:

Chamber Area, ft^2 ______
Cake Thickness, mm
Final: 1 3/16
Initial: ______
Dry Solids Density, g/cc: ______
Liquid Density, g/cc: ______

Data: g-ml ______ kg-l ______

Cake Weight:	Total	Part	Tare	
Wet:		241.7	32.4	S-5
Dry:		152.3		

Line # of Constant Pressure: ______
Output: Metric ______ English ______
Final 63.0 wt% solids
Feed : [illegible] [illegible] wt%

	Time minutes	Pressure psig	Volume		Time minutes	Pressure psig	Volume
1.	1	50	40	2.	25	50	400
3.	2	50	60	4.	30	50	442
5.	4	50	110	6.	35		485
7.	6	50	150	8.	Air blow 2.5	75	
9.	8	50	190	10.	Total	Vol =	522
11.	10	50	225	12.			
13.	12	50	250	14.			
15.	14		280	16.			
17.	16		300	18.			
19.	20		350	20.			

Filtrate pH: [illegible]

Filtrate Solids, mg/l: ______

Comments: (cake/filtrate description, chemical addition, etc.)

Try again w/o lime addition + at low pressure.
FILTRATE Clear
Air blow tail 2.5 min vol = 75 ml

EIMCO Process
Equipment
Company

EIMCO PROCESS EQUIPMENT COMPANY
LABORATORY PRESSURE FILTRATION DATA

Customer: [illegible]
Material: [illegible]
Cloth: [illegible]

Test No: 5
Test Date: [illegible]
Slurry Solids, wt%: ______

Laboratory Test Data:

Chamber Area, ft^2 ______
Cake Thickness, mm
Final: ~1/4
Initial: ______
Dry Solids Density, g/cc: ______
Liquid Density, g/cc: ______

Data: g-ml ______ kg-l ______

Cake Weight:	Total	Part	Tare
Wet:			
Dry:			

Line # of Constant Pressure: ______
Output: Metric ______ English ______

116
549
556

	Time minutes	Pressure psig	Volume		Time minutes	Pressure psig	Volume
1.	0.5	25	74	2.	7	50	353
3.	1.0	25	120	4.	8	50	375
5.	1.5	30	156	6.	9	50	406
7.	2.0	35	185	8.	10	50	426
9.	2.5	40	214	10.	~~8~~ 12	50	466
11.	3.0	45	236	12.	~~16~~ 14-15'	50	500
13.	3'-23"	45	250	14.	18	50	560
15.	4'	50	270	16.	23	50	627
17.	5	50	304	18.	30	50	706
19.	6	50	332	20.	36	50	770
					40	50	[illegible]35
					2' Air blow	70	⟷ 30

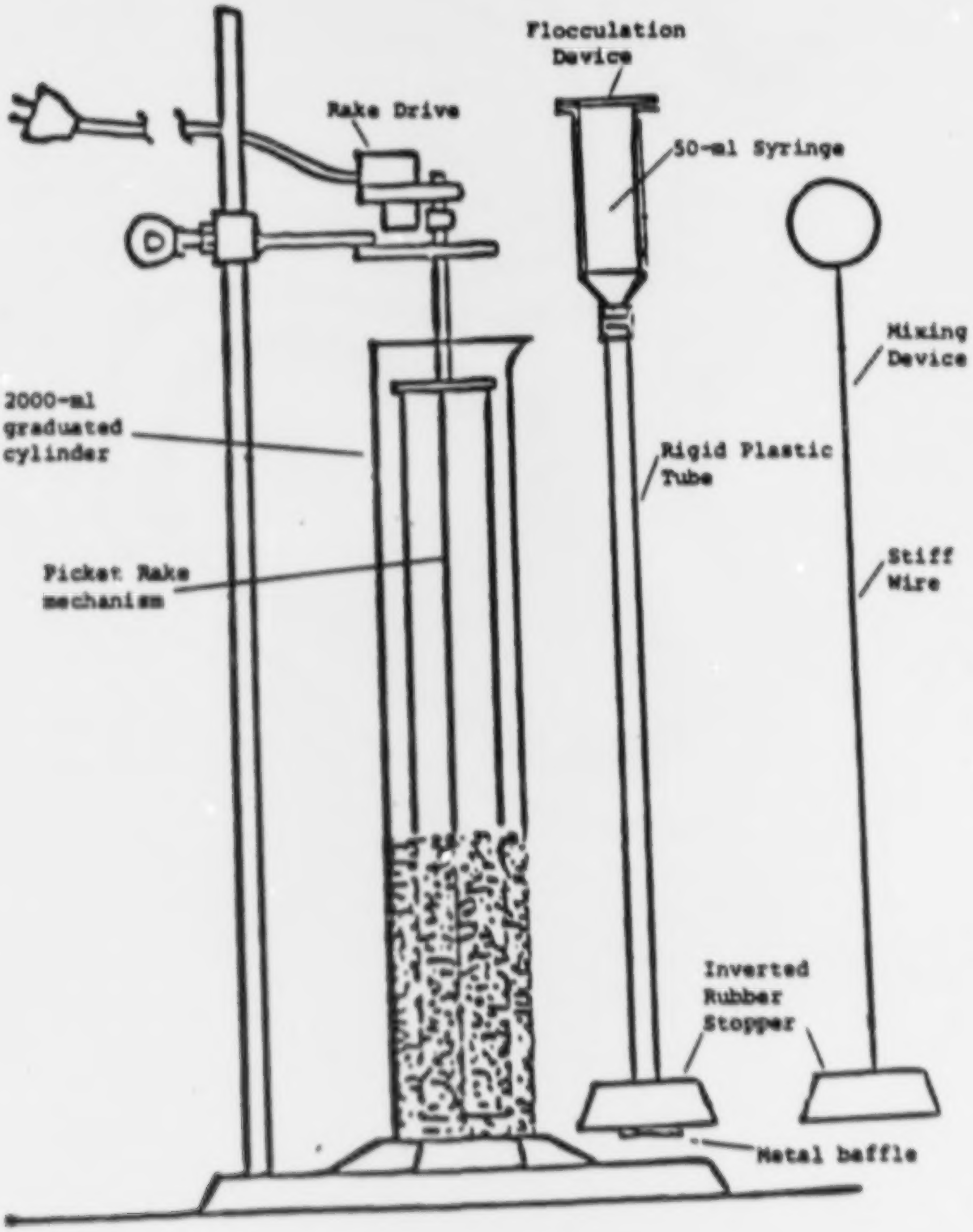
Filtrate pH: ______
Filtrate Solids, mg/l: ______

Comments: (cake/filtrate description, chemical addition, etc.)

Temp [illegible]

FIGURE A

THICKENING TEST APPARATUS


Flocculation Device
Rake Drive
50-ml Syringe
Mixing Device
2000-ml graduated cylinder
Rigid Plastic Tube
Picket Rake mechanism
Stiff Wire
Inverted Rubber Stopper
Metal baffle

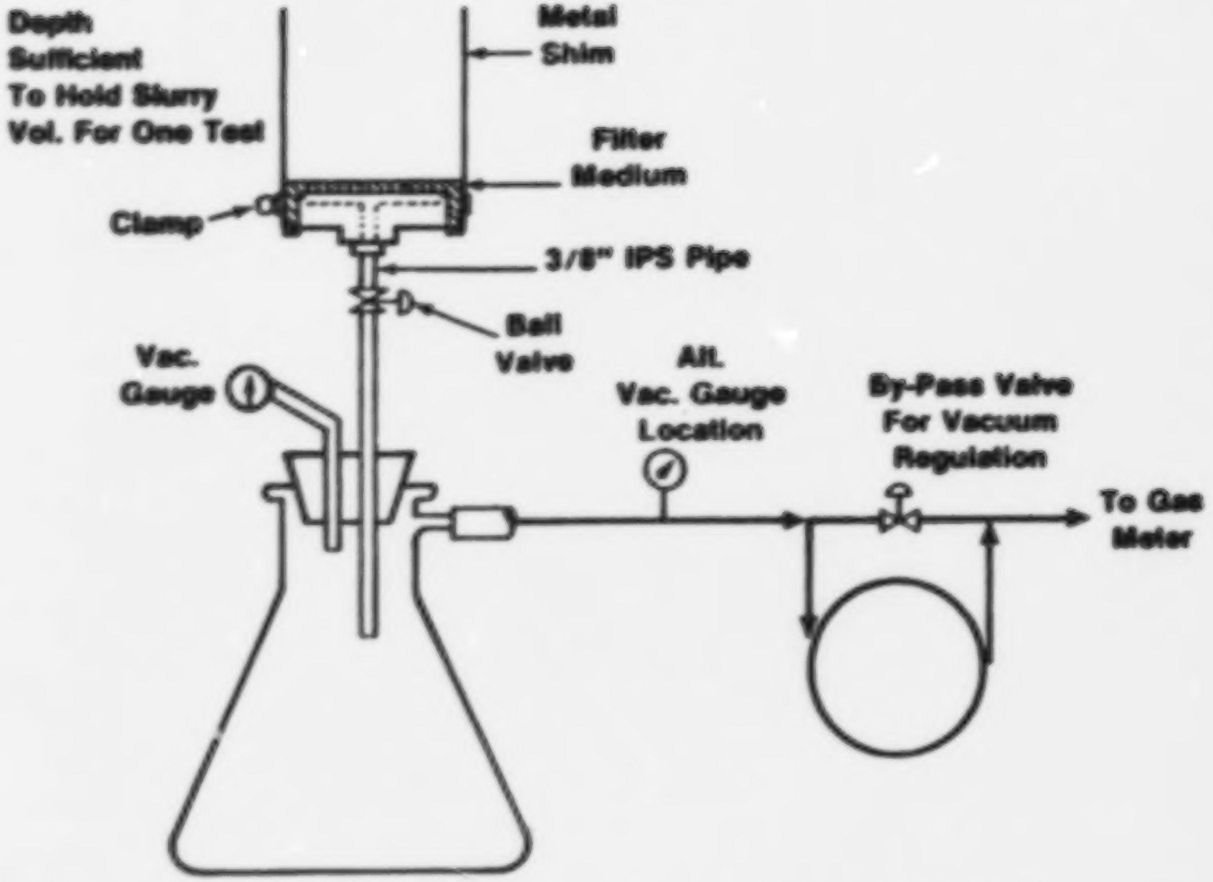

Depth
Sufficient
To Hold Slurry
Vol. For One Test
Metal
Shim
Filter
Medium
Clamp
3/8" IPS Pipe
Ball
Valve
Vac.
Gauge
Alt.
Vac. Gauge
Location
By-Pass Valve
For Vacuum
Regulation
To Gas
Meter

FIGURE TOP FEED LEAF TEST ARRANGEMENT

LAKEFIELD RESEARCH

185 Concession Street, Postal Bag 4300, Lakefield, Ontario, KOL 2HO

Facsimile No. (705) 652-6365
Telephone No. (705) 652-3341

To: Bill Stone	Company: EIMCO
From: WARREN REISHUS	Fax No: 705-689-8940
Date: July 27, 1992	Project No. 4307

This transmission consists of ____ pages including this one.

Attached is sample data for requested analysis.

1. Analysis for Ni; Samples S1 to S7
2. Screen Analysis 2A, 1B, 1D and sample
   #4 Filter Press Cake
3. Dry solids Wt.; Samples 1, 2, 3 & 4 Cakes
   #23 2nd Stage Apt.
4. SS on samples E1 through E56
   (E13 missing)

If you have any questions please do not hesitate to call.

Fin ≥

B. STONE

July 27/9[illegible]

1. Dry Solids Wt. (g)

#1	172.2	Filter Press Cakes
2	127.0	
3	172.5	
4	187.1	
#23	21.2	2nd Stage Ppt THKG.

2. Samples for Screen Anal. wt. (g)

2A	198.4
1B	356.7
1D	375.2

Sample #4 - Filter Press Cake 186.9

3. Soluble Ni Sample Analyses

S-1	63.9	mg/L
-2	79.5	"
-3	105	"
-4	158	"
-5	278	"
-6	410	"
-7	1210	"

Project No. 4294 Company 4294 Company

Sample No.		(mg/L) TSS			(mg/L) TSS
E1		6090	E35		30
E2		6015	E36		60
E3		5830	E37		58
E4		5620	E38		53
E5		4490	E39		43
E6		1025	E40		45
E7		424	E41		47
E8		256	E42		67
E9		268	E43		63
E10		276	E44		52
E11		212	E45		45
E12		182	E46		45
E14		5820	E47		45
E15		2740	E48		43
E16		280	E49		1378
E17		210	E50		113
E18		158	E51		55
E19		169	E52		37
E20		138	E53		42
E21		125	E54		38
E22		129	E55		37
E23		119	E56		30
E24		97			
E25		<28			
E26		113			
E27		68			
E28		55			
E29		42			
E30		47			
E31		53			
E32		47			
E33		49			
E34		<33			

* E13 missing

Project No: 4307 MB

Product: Elmco Thk. Test No: 1B

Microns	Mesh	Weight Grams	% Weight		
			Ind.	Cum.	Passing
208	65	1.6	1.3	1.3	98.7
147	100	5.1	4.1	5.4	94.6
104	150	11.7	9.4	14.8	85.1
74	200	14.6	11.8	26.6	73.4
53	270	14.2	11.5	38.1	61.9
38	400	14.9	12.0	50.1	49.9
-38	-400	61.8	49.9	100.0	-
	Total	123.9	100.0	-	-

Product: Elmco Thk. Test No: 1D

Microns	Mesh	Weight Grams	% Weight		
			Ind.	Cum.	Passing
208	65	0.8	0.7	0.7	99.3
147	100	4.0	3.3	4.0	96.0
104	150	8.1	6.7	10.7	89.3
74	200	10.5	8.7	19.4	80.6
53	270	12.1	10.0	29.5	70.5
38	400	13.5	11.2	40.7	59.3
-38	-400	71.4	59.3	100.0	-
	Total	120.4	100.0	-	-

Project No: 4307 MB

Product: Elmco Thk. Test No: 2A

Microns	Mesh	Weight Grams	% Weight		
			Ind.	Cum	Passing
208	65	5.7	4.5	4.5	95.5
147	100	11.1	8.7	13.2	86.8
104	150	19.2	15.1	28.3	71.7
74	200	17.3	13.6	41.9	58.1
53	270	15.2	11.9	53.9	46.1
38	400	10.5	8.3	62.1	37.9
-38	-400	48.2	37.9	100.0	-
	Total	127.2	100.0	-	-

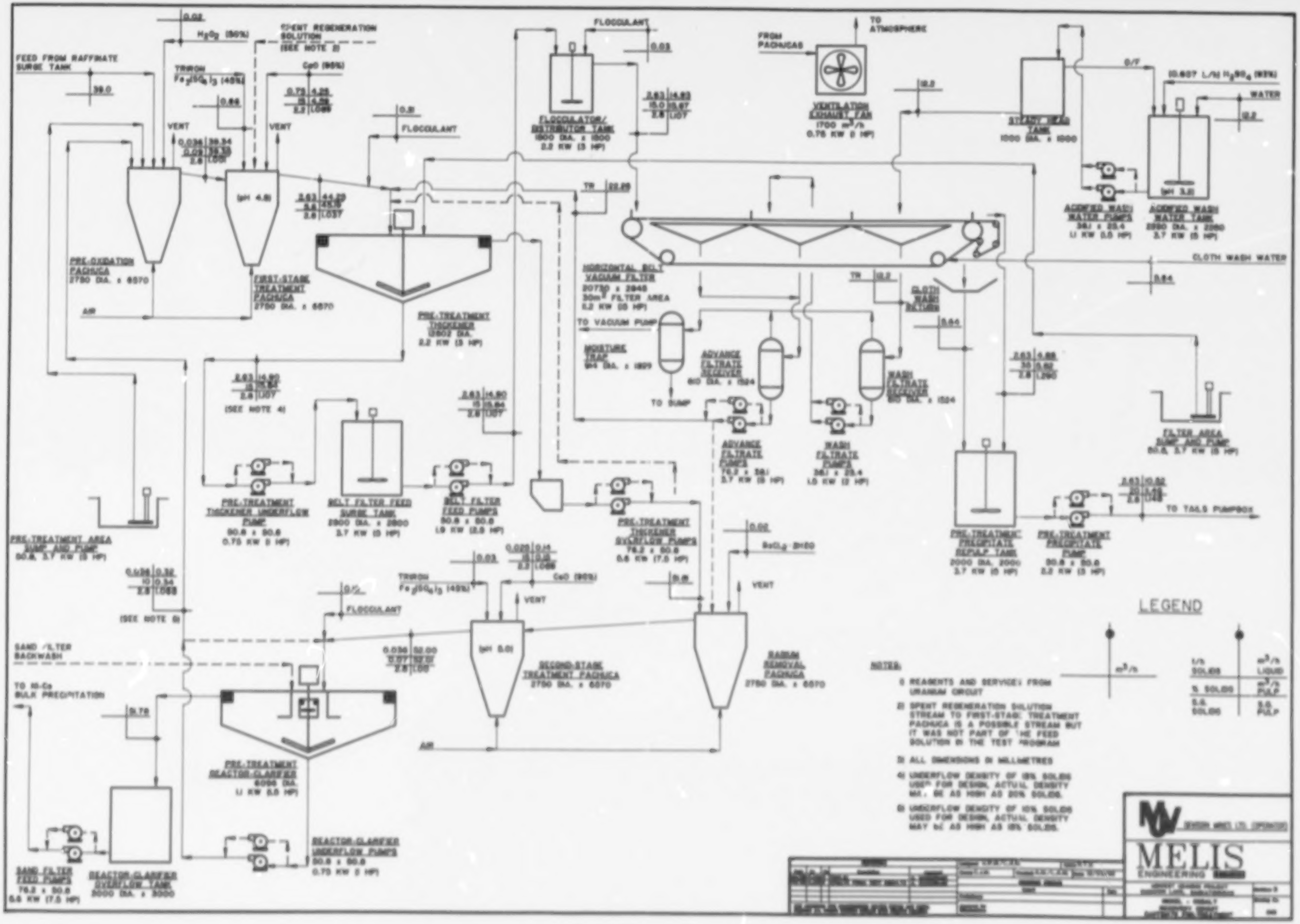
Product: Elmco FP Cake Test No: 4

Microns	Mesh	Weight Grams	% Weight		
			Ind.	Cum.	Passing
208	65	1.7	0.9	0.9	99.1
147	100	5.1	2.7	3.6	96.4
104	150	11.3	6.0	9.7	90.3
74	200	14.5	7.8	17.4	82.6
53	270	13.6	7.3	24.7	75.3
38	400	13.4	7.2	31.9	68.1
-38	-400	127.3	68.1	100.0	-
	Total	186.9	100.0	-	-

Appendix C

MELIS ENGINEERING LTD.

Process Flowsheets


FEED FROM RAFFINATE SURGE TANK
39.0
H_2O_2 (50%)
0.02
TIRRON $Fe_2(SO_4)_3$ (45%)
0.66
SPENT REGENERATION SOLUTION (SEE NOTE 2)
CaO (95%)
VENT
VENT
0.31
FLOCCULANT
PRE-OXIDATION PACHUCA 2750 DIA. x 6070
(pH 4.8)
FIRST-STAGE TREATMENT PACHUCA 2750 DIA. x 6070
AIR
PRE-TREATMENT THICKENER 12802 DIA. 2.2 KW (3 HP)
FLOCCULANT
0.03
FLOCCULATOR/ DISTRIBUTOR TANK 1500 DIA. x 1500 2.2 KW (3 HP)
FROM PACHUCAS
TO ATMOSPHERE
VENTILATION EXHAUST FAN 1700 m^3/h 0.75 KW (1 HP)
12.2
STEADY HEAD TANK 1000 DIA. x 1000
O/F
(0.607 L/h) H_2SO_4 (93%)
WATER
12.2
(pH 3.2)
ACIDIFIED WASH WATER PUMPS 38.1 x 25.4 1.1 KW (1.5 HP)
ACIDIFIED WASH WATER TANK 2290 DIA. x 2290 3.7 KW (5 HP)
TR
22.25
HORIZONTAL BELT VACUUM FILTER 20730 x 2845 30 m^2 FILTER AREA 5.2 KW (10 HP)
CLOTH WASH WATER
5.64
TR
12.2
CLOTH WASH RETURN
5.64
TO VACUUM PUMP
MOISTURE TRAP 914 DIA. x 1829
TO SUMP
ADVANCE FILTRATE RECEIVER 610 DIA. x 1524
WASH FILTRATE RECEIVER 610 DIA. x 1524
ADVANCE FILTRATE PUMPS 76.2 x 38.1 3.7 KW (5 HP)
WASH FILTRATE PUMPS 38.1 x 25.4 1.5 KW (2 HP)
FILTER AREA SUMP AND PUMP 50.8, 3.7 KW (5 HP)
(SEE NOTE 4)
PRE-TREATMENT THICKENER UNDERFLOW PUMP 50.8 x 50.8 0.75 KW (1 HP)
BELT FILTER FEED SURGE TANK 2800 DIA. x 2800 3.7 KW (5 HP)
BELT FILTER FEED PUMPS 50.8 x 50.8 1.5 KW (2.0 HP)
PRE-TREATMENT THICKENER OVERFLOW PUMPS 76.2 x 50.8 5.6 KW (7.5 HP)
PRE-TREATMENT PRECIPITATE REPULP TANK 2000 DIA. 2000 3.7 KW (5 HP)
PRE-TREATMENT PRECIPITATE PUMP 50.8 x 50.8 2.2 KW (3 HP)
TO TAILS PUMPBOX
PRE-TREATMENT AREA SUMP AND PUMP 50.8, 3.7 KW (5 HP)
(SEE NOTE 5)
0.02
$BaCl_2$ 2H2O
VENT
0.03
TIRRON $Fe_2(SO_4)_3$ (45%)
CaO (95%)
VENT
0.12
FLOCCULANT
SAND FILTER BACKWASH
TO Ni-Co BULK PRECIPITATION
0.78
(pH 8.0)
SECOND-STAGE TREATMENT PACHUCA 2750 DIA. x 6070
RADIUM REMOVAL PACHUCA 2750 DIA. x 6070
AIR
PRE-TREATMENT REACTOR-CLARIFIER 6096 DIA. 1.1 KW (1.5 HP)
SAND FILTER FEED PUMPS 76.2 x 50.8 5.6 KW (7.5 HP)
REACTOR-CLARIFIER OVERFLOW TANK 3000 DIA. x 3000
REACTOR-CLARIFIER UNDERFLOW PUMPS 50.8 x 50.8 0.75 KW (1 HP)
LEGEND
m^3/h
t/h SOLIDS
m^3/h LIQUID
% SOLIDS
m^3/h PULP
S.G. SOLIDS
S.G. PULP
DENISON MINES LTD. (OPERATOR)
MELIS ENGINEERING

NOTES:

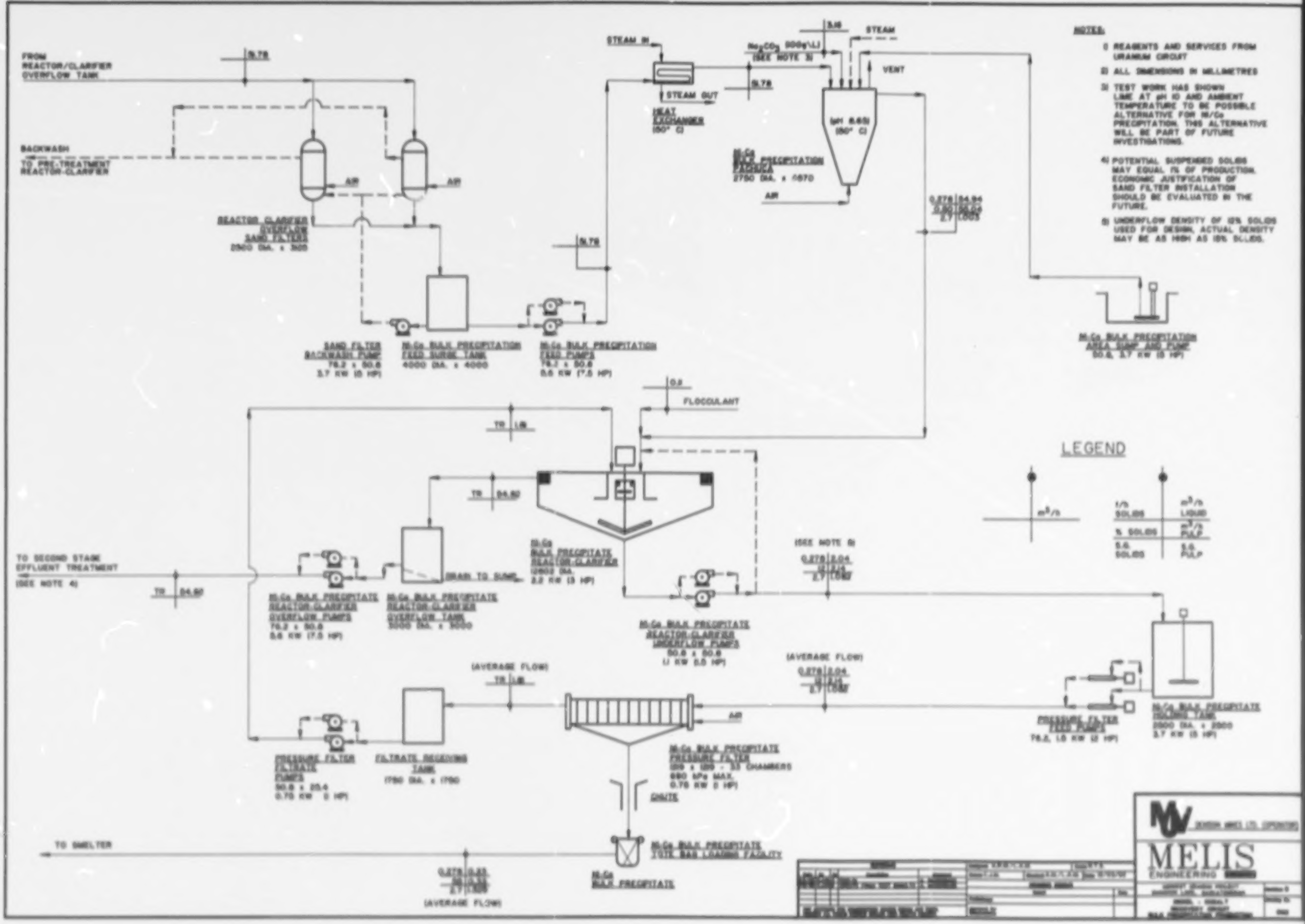
1) REAGENTS AND SERVICES FROM URANIUM CIRCUIT

2) SPENT REGENERATION SOLUTION STREAM TO FIRST-STAGE TREATMENT PACHUCA IS A POSSIBLE STREAM BUT IT WAS NOT PART OF THE FEED SOLUTION IN THE TEST PROGRAM

3) ALL DIMENSIONS IN MILLIMETRES

4) UNDERFLOW DENSITY OF 18% SOLIDS USED FOR DESIGN, ACTUAL DENSITY MAY BE AS HIGH AS 20% SOLIDS.

5) UNDERFLOW DENSITY OF 10% SOLIDS USED FOR DESIGN, ACTUAL DENSITY MAY BE AS HIGH AS 15% SOLIDS.


FROM REACTOR/CLARIFIER OVERFLOW TANK
5.78
BACKWASH
TO PRE-TREATMENT REACTOR-CLARIFIER
AIR
AIR
REACTOR CLARIFIER OVERFLOW SAND FILTERS
2500 DIA. x 3125
5.78
SAND FILTER BACKWASH PUMP
76.2 x 50.8
3.7 KW (5 HP)
Ni-Co BULK PRECIPITATION FEED SURGE TANK
4000 DIA. x 4000
Ni-Co BULK PRECIPITATION FEED PUMPS
76.2 x 50.8
5.6 KW (7.5 HP)
STEAM IN
STEAM OUT
HEAT EXCHANGER
(60° C)
5.78
Na_2CO_3 300g\L)
(SEE NOTE 1)
3.16
STEAM
VENT
(pH 8.65)
(60° C)
Ni-Co BULK PRECIPITATION PACHUCA
2750 DIA. x 6670
AIR
0.278
0.30
2.7
Ni-Co BULK PRECIPITATION AREA SUMP AND PUMP
50.8, 3.7 KW (5 HP)
0.2
FLOCCULANT
TR
TR
TO SECOND STAGE EFFLUENT TREATMENT
(SEE NOTE 4)
TR
Ni-Co BULK PRECIPITATE REACTOR-CLARIFIER OVERFLOW PUMPS
76.2 x 50.8
5.6 KW (7.5 HP)
Ni-Co BULK PRECIPITATE REACTOR-CLARIFIER OVERFLOW TANK
3000 DIA. x 3000
DRAIN TO SUMP
Ni-Co BULK PRECIPITATE REACTOR-CLARIFIER
12802 DIA.
2.2 KW (3 HP)
Ni-Co BULK PRECIPITATE REACTOR-CLARIFIER UNDERFLOW PUMPS
50.8 x 50.8
(.1 KW 0.5 HP)
(SEE NOTE 5)
0.278
2.7
(AVERAGE FLOW)
TR
(AVERAGE FLOW)
0.278
2.7
AIR
PRESSURE FILTER FILTRATE PUMPS
50.8 x 25.4
0.75 KW (1 HP)
FILTRATE RECEIVING TANK
1750 DIA. x 1750
Ni-Co BULK PRECIPITATE PRESSURE FILTER
1200 x 1200 - 33 CHAMBERS
690 kPa MAX.
0.75 KW (1 HP)
CHUTE
PRESSURE FILTER FEED PUMPS
76.2, 1.5 KW (2 HP)
Ni-Co BULK PRECIPITATE HOLDING TANK
2500 DIA. x 2500
3.7 KW (5 HP)
TO SMELTER
0.278
2.7
(AVERAGE FLOW)
Ni-Co BULK PRECIPITATE
Ni-Co BULK PRECIPITATE TOTE BAG LOADING FACILITY
LEGEND
m^3/h
t/h SOLIDS
% SOLIDS
S.G. SOLIDS
m^3/h LIQUID
m^3/h PULP
S.G. PULP
DENISON MINES LTD. (OPERATOR)
MELIS
ENGINEERING

NOTES:

1) REAGENTS AND SERVICES FROM URANIUM CIRCUIT

2) ALL DIMENSIONS IN MILLIMETRES

3) TEST WORK HAS SHOWN LIME AT pH 10 AND AMBIENT TEMPERATURE TO BE POSSIBLE ALTERNATIVE FOR Ni/Co PRECIPITATION. THIS ALTERNATIVE WILL BE PART OF FUTURE INVESTIGATIONS.

4) POTENTIAL SUSPENDED SOLIDS MAY EQUAL 1% OF PRODUCTION. ECONOMIC JUSTIFICATION OF SAND FILTER INSTALLATION SHOULD BE EVALUATED IN THE FUTURE.

5) UNDERFLOW DENSITY OF 12% SOLIDS USED FOR DESIGN. ACTUAL DENSITY MAY BE AS HIGH AS 15% SOLIDS.

Appendix D

MELIS ENGINEERING LTD.

Capital Cost Estimate Details

MELIS ENGINEERING LTD.
PROJECT NO. 258

MIDWEST JOINT VENTURE
NICKEL-COBALT RECOVERY CIRCUIT
CAPITAL COST ESTIMATE DETAILS
(COST DATA ADAPTED FROM MIDWEST FEASIBILITY STUDY AND FILE DATA)

DATE: AUGUST 20, 1992
CURRENCY: CANADIAN DOLLARS
3RD QUARTER 1992

DIRECT COSTS

AREA:	TOTAL MANHOURS	TOTAL LABOUR	TOTAL MATERIAL	TOTAL COSTS
FIRST-STAGE PRE-TREATMENT	2,855	114,200	736,125	850,325
FIRST-STAGE PRECIPITATE FILTRATION	3,855	154,200	994,251	1,148,451
SECOND-STAGE PRE-TREATMENT	2,095	83,800	492,041	575,841
NICKEL/COBALT BULK PRECIPITATION	3,650	146,000	806,850	952,850
REAGENTS AND SERVICES	19,000	76,000	394,400	470,400
BUILDING	6,300	252,000	624,600	876,600
TOTAL DIRECT COSTS	37,755	826,200	4,048,267	4,874,467

INDIRECT COSTS

ENGINEERING, PROCUREMENT, CONSTRUCTION MANAGEMENT	500,000
CAMP COSTS	125,000
TURNAROUND	50,000
MOBILIZATION AND DEMOBILIZATION	50,000
CONSTRUCTION EQUIPMENT AND SMALL TOOLS	100,000
OWNER'S COSTS	250,000
TOTAL INDIRECT COSTS	1,075,000
TOTAL DIRECT AND INDIRECT COSTS	5,949,467
CONTINGENCY	595,000
TOTAL ESTIMATED CAPITAL COSTS	6,544,467

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Appendix E

Project Milestone Report 1

MIDWEST JOINT VENTURE
Denison Mines Limited (Operator)

TO: R. Mainer

DATE: March 30, 1992

FROM: A. R. Marchbank

FILE: 5891-007

SUBJECT: Nickel/Cobalt Recovery from Midwest Raffinate; First Milestone Report

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The following report represents the first progress report, fulfilling the Midwest Joint Venture requirements for the first milestone payment, under Contract No. 23440-1-9153/01-SQ. Please find attached the Lakefield Research Progress Report No. 1, 4324, Investigation of The Recovery of Nickel and Cobalt from Midwest Uranium Raffinate.

Introduction

The first stage of the nickel and cobalt recovery research at Lakefield Research is complete and a progress report has been submitted. Using the preliminary results obtained, a projected plant design and operating and capital costs have been prepared by MJV to permit planning of the second phase of the research. This report contains a brief summary of the projected capital and operating costs associated with the most likely alternative as well as the expected revenues. Justification of the selection of the chosen option is also included. It must be noted that the estimates presented are very rough, but are expected to be reasonably accurate, given the preliminary nature of the research. It should be noted that the capital and operating cost information presented is taken from the Midwest Joint Venture feasibility study. Since that study is a confidential document, precise details are not included with this report. However, since this is a preliminary review, this basis of calculation is considered to be sufficient. During the development of a prefeasibility study in the later stages of the project, more complete documentation will be provided.

Process Summary

The selected alternative which will be further pursued in the second phase of the research, is production of a bulk nickel/cobalt precipitate. The raffinate will be purified by removal of arsenic, radium, iron and aluminum as well as various other minor impurities in a precipitation circuit similar to that already planned for first stage effluent treatment. The purified raffinate can then be neutralized with sodium carbonate to produce a bulk nickel/cobalt carbonate precipitate containing 40% nickel and 4% cobalt. This material will be thickened and the slurry pressure filtered to produce a cake which will be packed in tote bags for shipment to further refining. Flow diagrams for this process are attached as Drawings No. Ni-Co-001 and 002.

Potential Revenues

The potential revenues from treatment of the raffinate are based upon the solution grades attained during the main body of metallurgical testing carried out during development of the feasibility study. Recovery of nickel during this work was very poor, cobalt recovery, while better, was still very low. The final projected production here is an overall recovery from ore of 31% of the nickel and 44% of the cobalt. The majority of this loss (90%) comes from poor leach extraction and, since no other tests have produced such poor extraction of these metals, the production estimates presented here must be considered a worst case scenario by a considerable margin.

The projected revenues are based upon numbers supplied by Falconbridge Ltd.

Nickel Price:	$3.25/lb
Reimbursement:	80% of value
Refining Charges:	$0.65/lb
Cobalt Price:	$28.50/lb
Reimbursement:	65% of value
Refining Charges:	$1.30/lb
Smelter Charges:	$190/ton of concentrate
Transport Cost:	$90/ton

Estimated nickel recovery is 1,012,320 lbs per year which, exclusive of smelter and transport charges, should yield a net return of $1,974,024. At 10% of the nickel production level, calculated on the same basis, cobalt will yield $1,723,475. The total tonnage of concentrate will be 1265 tons, which will result in total smelter charges of $240,350 and transport costs of $113,850. The net return will be $3,343,299. Since all numbers quoted are in U.S. dollars, the revenue in Canadian funds is estimated to be $3.95 million per year.

Operating Costs

It is expected that one additional operator, on each shift, will be required to operate the nickel circuit, no other additional labour requirements are anticipated. The only reagent requirements which are incremental to the presently designed circuit are hydrogen peroxide and sodium carbonate. Since sodium carbonate will, to a small extent, be replacing lime in the circuit, a credit has been applied to this consumption. It should be noted that, since the second phase of the research will partially consist of optimization of the process, the reagent requirements listed can be expected to drop. Supplies and services are included at 14% of the total, similar to the cost listed in the feasibility study. Energy consumption is based upon projections for similar equipment which is listed in the feasibility study.

Labour:	4 men @ $50,000/year	$200,000
Reagents:	Sodium Carbonate: $363,000	
	Hydrogen Peroxide $148,000	$511,000
Energy:		$124,000
Supplies and Services:		$136,000
Total		$971,000

Net return per year will therefore be approximately $3 million.

Capital Cost

A preliminary equipment list was made up for the project, sizing the equipment for the maximum flow which can be expected in this circuit. The equipment was costed on the basis of quotations received for the feasibility study. This total cost was then inflated by a factor similar to that calculated in detail for similar circuits in the uranium plant (an average of 1.54) to arrive at a total direct cost. This total was then further increased by 40% to cover such costs as E.P.C.M., Indirects, Operator Compensation, etc. Finally, the numbers were increased by approximately 10% as an allowance for increased building costs (It should be noted that excavation and concrete work are covered in the first 54% factor).

Total Capital Cost: $3.23 million

The first stage effluent treatment circuit can be eliminated from the mill design since this circuit effectively replaces it. This is a saving of approximately $1.63 million if calculated on the same basis as the nickel circuit.

Net Capital Cost: $3.6 million

Payback Period: Approximately 15 months

Alternative Recovery Method

The second option which could be pursued was developed successfully in the first stage of the research program. The flow diagrams illustrating this method are contained in drawings No. Ni-Co-001 and 003. The process uses the purified raffinate generated in flow diagram 001 as feed for a solvent extraction circuit which removes cobalt from the raffinate stream leaving a pure nickel solution which is suitable for production of a pure nickel carbonate concentrate. The cobalt-loaded organic would be stripped to produce a pure cobalt sulphate solution suitable for production of a cobalt carbonate concentrate.

Using the same basis of calculation, it is estimated that net capital costs would increase to $6.6 million. Separating the cobalt from the nickel would probably only increase the value of the cobalt. It is estimated, therefore, that revenues would increase by approximately $625,000. However, operating costs would increase by a larger amount, reagent costs alone would increase by approximately $640,000. There can be no real payback for separating the nickel and cobalt, largely because of the high cost of reagents in Northern Saskatchewan.

Conclusion

While the numbers presented in this document are very preliminary, they do indicate that this project is an attractive one. Net return for the expected life of the project is expected to be in excess of $25 million. The additional capital outlay is a small proportion of the total project expenditure. The second phase of the research project, beginning in early April, will further investigate the design and operating parameters of the chosen alternative.

It is anticipated that the financial projections listed here will be estimated much more accurately by the end of the summer following completion of the test program. However, it must be emphasized that the numbers are presented in a very conservative manner. There is a good possibility that the final projected return on investment will be higher than shown here after more detailed work is complete. For example, the leach test upon which these numbers are based had nickel extraction at 38%. Since an accepted number for expected extraction is closer to 63%, it is possible that a higher overall recovery will be achieved. If the overall nickel recovery were to increase to 50%, with a corresponding increase in cobalt recovery, revenue would rise to $6.4 million. Net profit annually would increase to $3.4 million, and the project payback period would drop to 8 months.

If there are any questions concerning this report or the attached documents, I will be pleased to discuss them at the meeting April 3 at Lakefield Research.

A. R. Marchbank
Senior Metallurgist